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Liu et al.

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(54) **TECHNIQUE OF REDUCING SIZE OF BINARY JSON WITH/WITHOUT COMPRESSION**

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(73) Assignee: **Oracle International Corporation**, Redwood Shores, CA (US)

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(51) **Int. Cl.**
G06F 16/17 (2019.01)
G06F 16/11 (2019.01)
G06F 16/174 (2019.01)

(52) **U.S. Cl.**
CPC ***G06F 16/1744*** (2019.01); ***G06F 16/116*** (2019.01); ***G06F 16/1748*** (2019.01)

(58) **Field of Classification Search**
CPC . G06F 16/1744; G06F 16/116; G06F 16/1748
USPC 707/692
See application file for complete search history.

(56) **References Cited**

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2006/0212467	A1 *	9/2006	Murthy	G06F 40/123
2007/0260571	A1 *	11/2007	Mansfield	G06F 40/154 706/48
2007/0271305	A1 *	11/2007	Chandrasekar	G06F 16/86
2017/0060912	A1 *	3/2017	Liu	G06F 16/2255
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2020/0226102	A1 *	7/2020	Natanzon	G06F 16/1744
2021/0117611	A1 *	4/2021	Liu	H03M 7/4031

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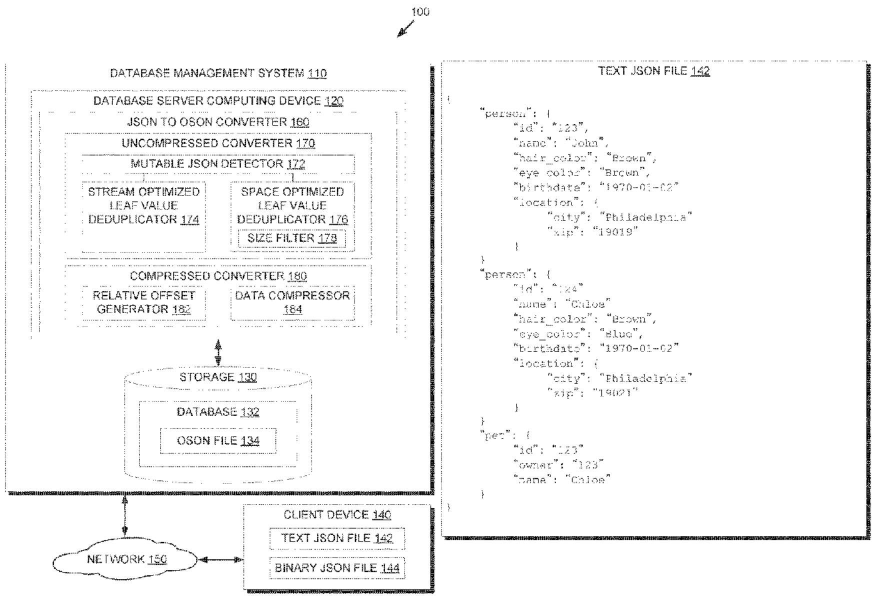
(57) **ABSTRACT**

Data structures and methods are described for converting a text format data-interchange file into size efficient binary representations. A method comprises receiving a request to convert a data-interchange file, comprising a hierarchy of nodes, into a binary file. The method further comprises generating a tree representation of the nodes that reference a plurality of leaf values. The method further comprises, in response to determining that the binary file is to be compressed, embedding relative node jump offsets when generating the tree representation. The method further comprises, in response to determining that the data-interchange file is immutable, deduplicating the plurality of leaf values in a space optimized manner. The method further comprises, in response to determining that the data-interchange file is mutable, deduplicating the plurality of leaf values in a stream optimized manner. The method further comprises storing the deduplicated plurality of leaf values in the binary file.

20 Claims, 14 Drawing Sheets


100
DATABASE MANAGEMENT SYSTEM 110
DATABASE SERVER COMPUTING DEVICE 120
JSON TO OSON CONVERTER 160
UNCOMPRESSED CONVERTER 170
MUTABLE JSON DETECTOR 172
STREAM OPTIMIZED LEAF VALUE DEDUPLICATOR 174
SPACE OPTIMIZED LEAF VALUE DEDUPLICATOR 176
SIZE FILTER 178
COMPRESSED CONVERTER 180
RELATIVE OFFSET GENERATOR 182
DATA COMPRESSOR 184
STORAGE 130
DATABASE 132
OSON FILE 134
CLIENT DEVICE 140
TEXT JSON FILE 142
BINARY JSON FILE 144
NETWORK 150
TEXT JSON FILE 142

```
{
    "person": {
        "id": "123",
        "name": "John",
        "hair_color": "Brown",
        "eye color": "Brown",
        "birthdate": "1970-01-02"
        "location": {
            "city": "Philadelpaia"
            "zip": "19019"
        }
    }
    "person": {
        "id": "124"
        "name": "Chloe"
        "hair_color": "Brown",
        "eye_color": "Blue",
        "birthdate": "1970-01-02"
        "location": {
            "city": "Philadelphia"
            "zip": "19021"
        }
    }
    "pet": {
        "id": "123"
        "owner": "123"
        "name": "Chloe"
    }
}
```

FIG. 1A

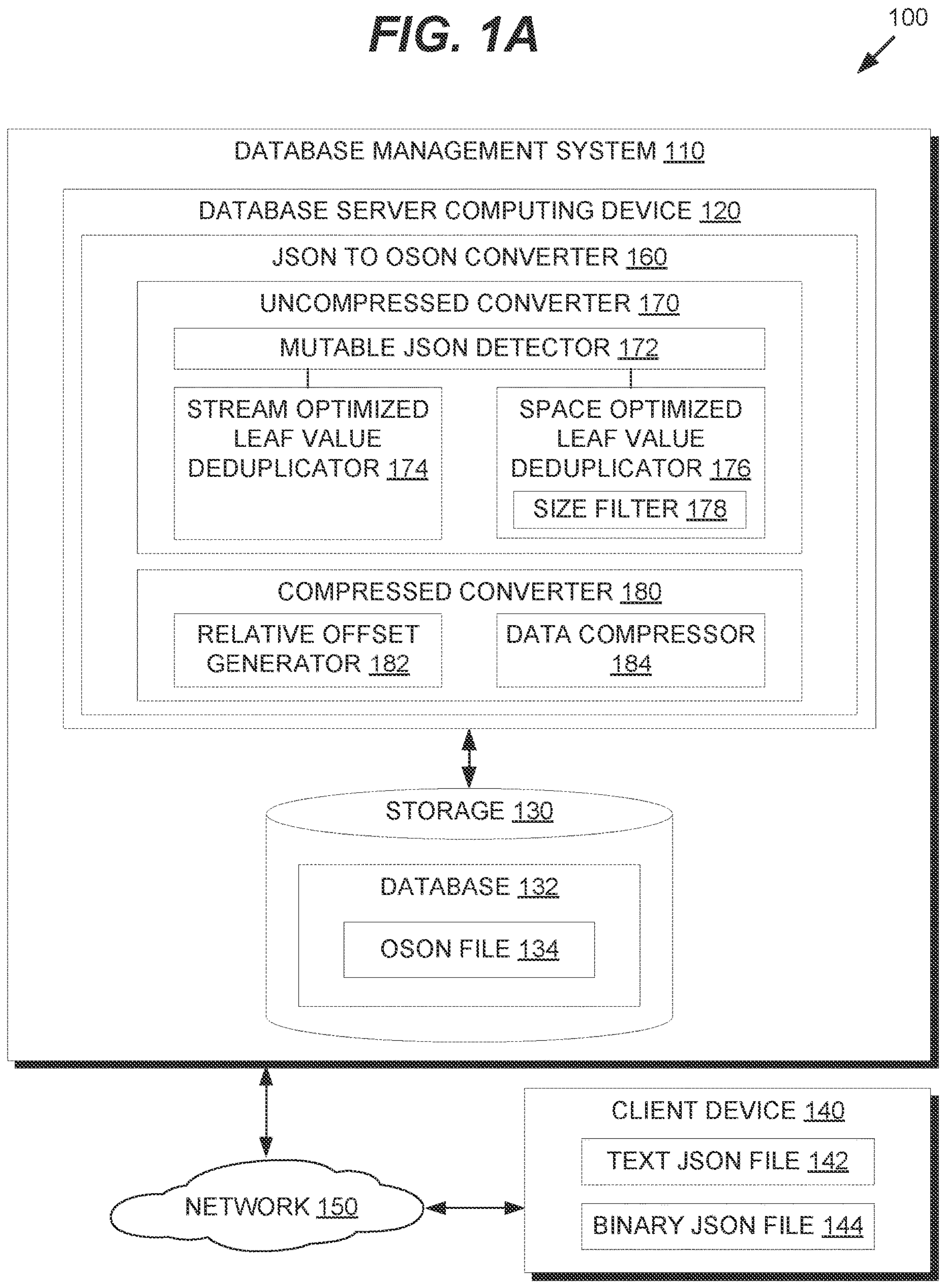
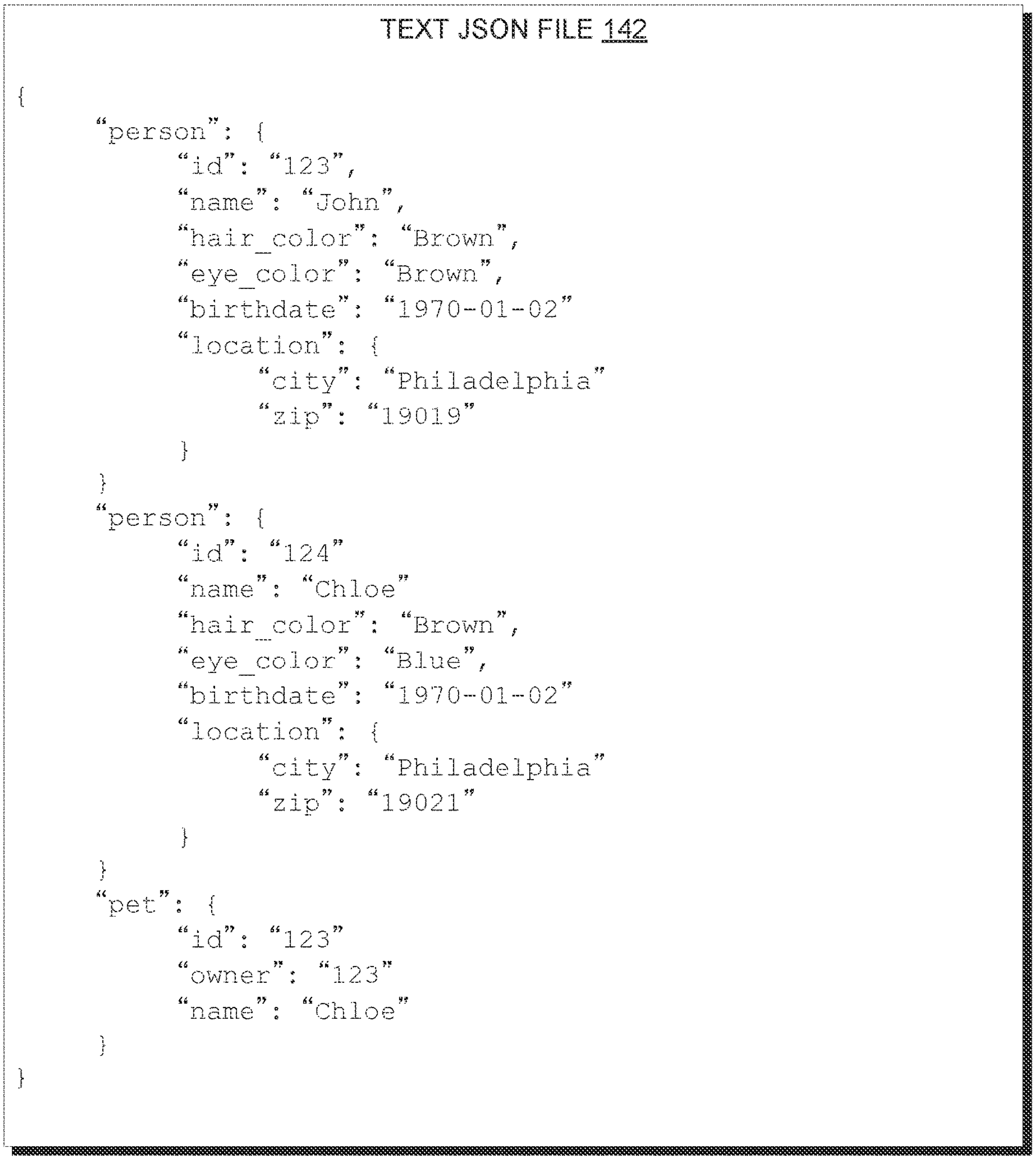

100
DATABASE MANAGEMENT SYSTEM 110
DATABASE SERVER COMPUTING DEVICE 120
JSON TO OSON CONVERTER 160
UNCOMPRESSED CONVERTER 170
MUTABLE JSON DETECTOR 172
STREAM OPTIMIZED LEAF VALUE DEDUPLICATOR 174
SPACE OPTIMIZED LEAF VALUE DEDUPLICATOR 176
SIZE FILTER 178
COMPRESSED CONVERTER 180
RELATIVE OFFSET GENERATOR 182
DATA COMPRESSOR 184
STORAGE 130
DATABASE 132
OSON FILE 134
CLIENT DEVICE 140
TEXT JSON FILE 142
BINARY JSON FILE 144
NETWORK 150

FIG. 1B



TEXT JSON FILE 142

```
{
     “person”: {
          “id”: “123”,
          “name”: “John”,
          “hair_color”: “Brown”,
          “eye_color”: “Brown”,
          “birthdate”: “1970-01-02”
          “location”: {
               “city”: “Philadelphia”
               “zip”: “19019”
          }
     }
     “person”: {
          “id”: “124”
          “name”: “Chloe”
          “hair_color”: “Brown”,
          “eye_color”: “Blue”,
          “birthdate”: “1970-01-02”
          “location”: {
               “city”: “Philadelphia”
               “zip”: “19021”
          }
     }
     “pet”: {
          “id”: “123”
          “owner”: “123”
          “name”: “Chloe”
     }
}
```

FIG. 2

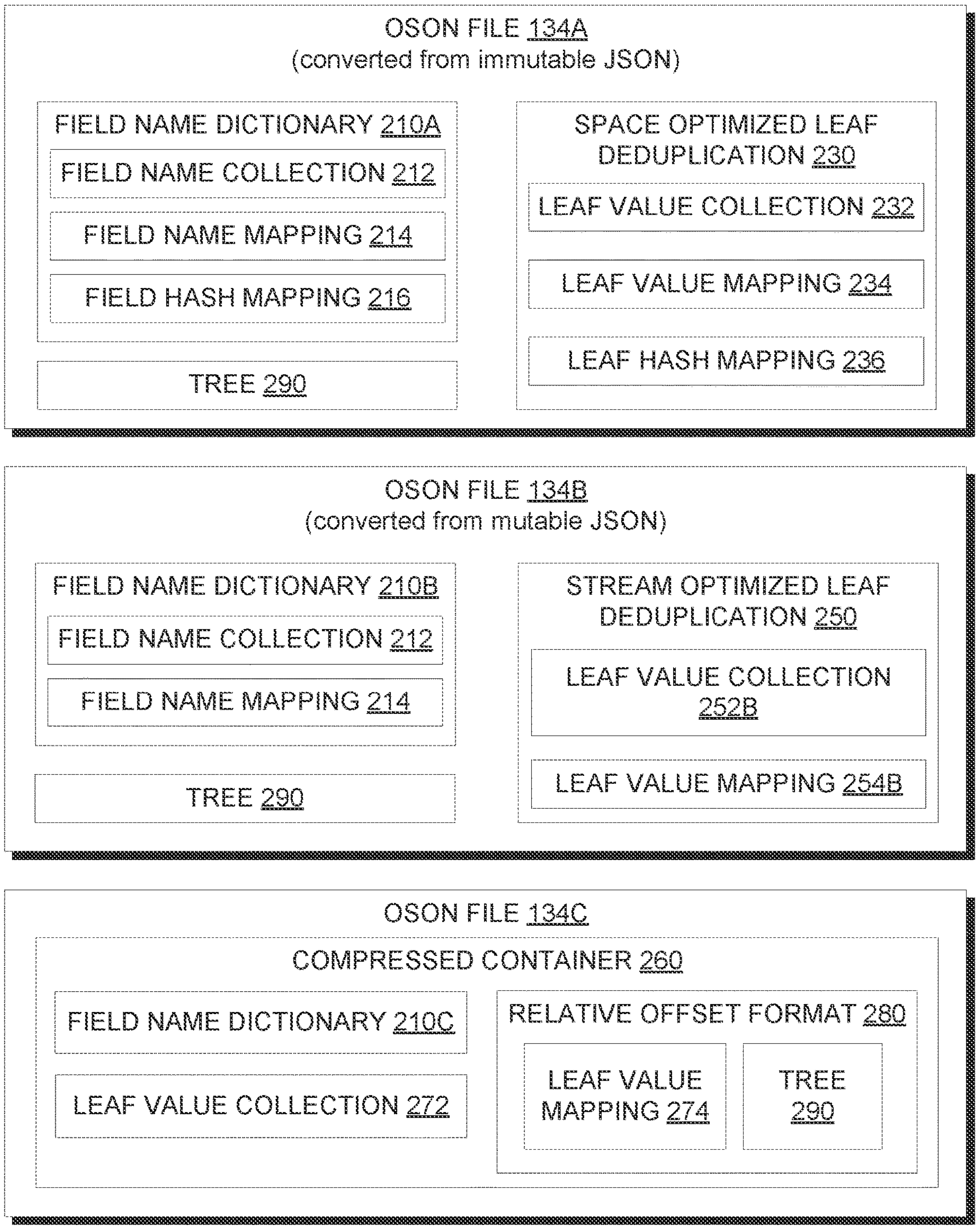

OSON FILE 134A
(converted from immutable JSON)
FIELD NAME DICTIONARY 210A
FIELD NAME COLLECTION 212
FIELD NAME MAPPING 214
FIELD HASH MAPPING 216
TREE 290
SPACE OPTIMIZED LEAF DEDUPLICATION 230
LEAF VALUE COLLECTION 232
LEAF VALUE MAPPING 234
LEAF HASH MAPPING 236
OSON FILE 134B
(converted from mutable JSON)
FIELD NAME DICTIONARY 210B
FIELD NAME COLLECTION 212
FIELD NAME MAPPING 214
TREE 290
STREAM OPTIMIZED LEAF DEDUPLICATION 250
LEAF VALUE COLLECTION 252B
LEAF VALUE MAPPING 254B
OSON FILE 134C
COMPRESSED CONTAINER 260
FIELD NAME DICTIONARY 210C
LEAF VALUE COLLECTION 272
RELATIVE OFFSET FORMAT 280
LEAF VALUE MAPPING 274
TREE 290

FIG. 3A

TABLE 300

(Example Field Name Dictionary 210A-210C)

FIELD NAME IDENTIFIERS 302	FIELD NAMES 304	HASH CODES 306	TRUNCATED HASH CODES 308
0x01	"birthdate"	0x1B64F409...	0x1B
0x02	"city"	0x4ED5D2EA...	0x4E
0x03	"pet"	0x6C43C0A8...	0x6C
0x04	"owner"	0x72122CE9...	0x72
0x05	"person"	0x8B0A4404...	0x8B
0x06	"zip"	0xADCDBD79...	0xAD
0x07	"name"	0xB068931C...	0xB0
0x08	"id"	0xB80BB774...	0xB8
0x09	"eye_color"	0xC5A9E390...	0xC5
0x0A	"location"	0xD5189DE0...	0xD5
0x0B	"hair_color"	0xEDAF4A8E...	0xED

FIELD NAME COLLECTION 212

Offset	Field Name
0x0000	0x06 "person"
0x0007	0x02 "id"
0x000A	0x04 "name"
0x000F	0x0A "hair_color"
0x001A	0x09 "eye_color"
0x0024	0x09 "birthdate"
0x002E	0x08 "location"
0x0037	0x04 "city"
0x003C	0x03 "zip"
0x0040	0x03 "pet"
0x0044	0x05 "owner"

Raw Data:

```
06706572736F6E026964046E616D65
0A686169725F636F6C6F7209657965
5F636F6C6F720962697274686461 74
65086C6F636174696F6E0463697479
037A697003706574056F776E6572
```

FIELD NAME MAPPING 214

Field ID	Offset
0x01	0x0024
0x02	0x0037
0x03	0x0040
0x04	0x0044
0x05	0x0000
0x06	0x003C
0x07	0x000A
0x08	0x0007
0x09	0x001A
0x0A	0x002E
0x0B	0x000F

Raw Data:

```
0024003700400044
0000003C000A0007
001A002E000F
```

FIELD HASH MAPPING 216

T.Hashcode
0x1B
0x4E
0x6C
0x72
0x8B
0xAD
0xB0
0xB8
0xC5
0xD5
0xED

Raw Data:

```
1B4E6C72
8BADB0B8
C5D5ED
```

FIG. 3B

(Example Space Optimized Deduplication 230)

TABLE 320

LEAF VALUE IDENTIFIERS 322	LEAF VALUES 324	HASH CODES 326	TRUNCATED HASH CODES 328
0x01	"19021"	0x159FC249...	0x15
0x02	"19019"	0x16D459C4...	0x16
0x03	"123"	0x202CB962...	0x20
0x04	"Philadelphia"	0x3064B320...	0x30
0x05	"1970-01-02"	0x5551D456...	0x55
0x06	"John"	0x61409AA1...	0x61
0x07	"Blue"	0x9594EEC9...	0x95
0x08	"Chloe"	0xC810B2DB...	0xC8
0x09	"124"	0xC8FFE9A5...	0xC8
0x0A	"Brown"	0xED63FC91...	0xED

LEAF VALUE COLLECTION 232

Offset	Leaf Value
0x0000	0x03 "123"
0x0004	0x04 "John"
0x0009	0x05 "Brown"
0x0010	0x0A "1970-01-02"
0x001A	0x0C "Philadelphia"
0x0027	0x05 "19019"
0x002D	0x03 "124"
0x0031	0x05 "Chloe"
0x0037	0x04 "Blue"
0x003C	0x05 "19021"

Raw Data:

```
03313233044A6F686E0542726F776E
0A313937302D30312D30320C506869
6C6164656C70686961053139303139
033132340543686C6F6504426C7565
053139303231
```

LEAF VALUE MAPPING 234

Leaf ID	Offset
0x01	0x003C
0x02	0x0027
0x03	0x0000
0x04	0x001A
0x05	0x0010
0x06	0x0004
0x07	0x0037
0x08	0x0031
0x09	0x002D
0x0A	0x0009

Raw Data:

```
003C00270000001A
0010000400370031
002D0009
```

LEAF HASH MAPPING 236

T.Hashcode
0x15
0x16
0x20
0x30
0x55
0x61
0x95
0xC8
0xC8
0xED

Raw Data:

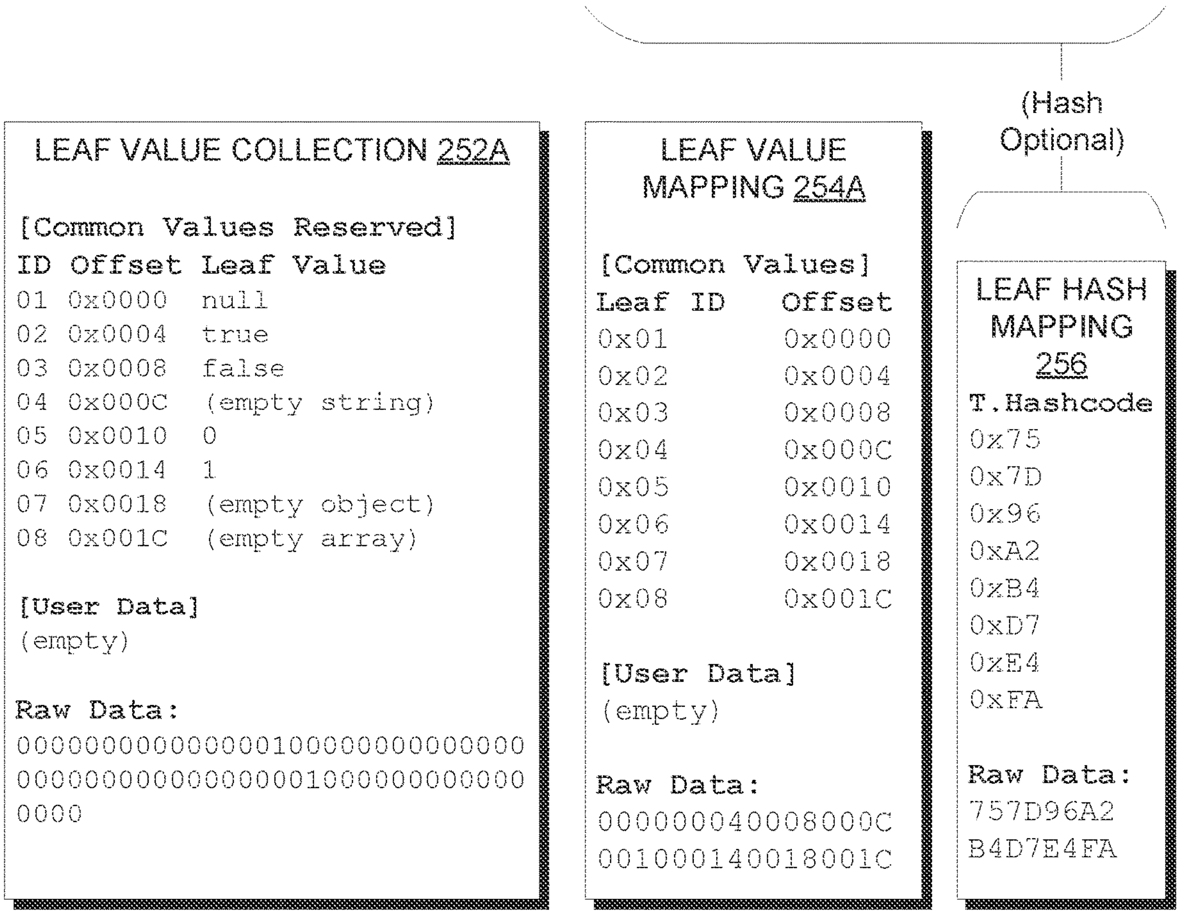
```
15162030
556195C8
C8ED
```

FIG. 3C

TABLE 340

(Example default dictionary reservations for common leaf values)

LEAF VALUE IDENTIFIERS 342	LEAF VALUES 344	HASH CODES 346	TRUNCATED HASH CODES 348
0x01	null	0x751D31DD...	0x75
0x02	true	0x7D066543...	0x7D
0x03	false	0x96A3BE3C...	0x96
0x04	(empty string)	0xA2EF406E...	0xA2
0x05	0	0xB4B147BC...	0xB4
0x06	1	0xD72D187D...	0xD7
0x07	(empty object)	0xE45EE7CE...	0xE4
0x08	(empty array)	0xFAEAC4E1...	0xFA



LEAF VALUE COLLECTION 252A

```
[Common Values Reserved]
ID Offset Leaf Value
01 0x0000 null
02 0x0004 true
03 0x0008 false
04 0x000C (empty string)
05 0x0010 0
06 0x0014 1
07 0x0018 (empty object)
08 0x001C (empty array)

[User Data]
(empty)

Raw Data:
0000000000000000100000000000000
0000000000000000001000000000000
0000
```

LEAF VALUE MAPPING 254A

```
[Common Values]
Leaf ID    Offset
0x01       0x0000
0x02       0x0004
0x03       0x0008
0x04       0x000C
0x05       0x0010
0x06       0x0014
0x07       0x0018
0x08       0x001C

[User Data]
(empty)

Raw Data:
000000040008000C
001000140018001C
```

LEAF HASH MAPPING 256

```
T.Hashcode
0x75
0x7D
0x96
0xA2
0xB4
0xD7
0xE4
0xFA

Raw Data:
757D96A2
B4D7E4FA
```

FIG. 3D

(Example Stream Optimized Deduplication 250)

LEAF VALUE COLLECTION 252B

[Common Values Reserved]

ID	Offset	Leaf Value
01	0x0000	null
02	0x0004	true
03	0x0008	false
04	0x000C	(empty string)
05	0x0010	0
06	0x0014	1
07	0x0018	(empty object)
08	0x001C	(empty array)

[User Data]

ID	Offset	Leaf Value
09	0x0020	0x03 "123"
0A	0x0024	0x04 "John"
0B	0x0029*	0x05 "Brown"
0C	0x002F	0x0A "1970-01-02"
0D	0x003A	0x0C "Philadelphia"
0E	0x0047	0x05 "19019"
0F	0x004D	0x03 "124"
10	0x0051	0x05 "Chloe"
11	0x0057	0x05 "Brown"
12	0x005D	0x04 "Blue"
13	0x0062	0x0A "1970-01-02"
14	0x006D	0x0C "Philadelphia"
15	0x007A	0x05 "19021"
16	0x0080*	0x03 "123"
17	0x0084	0x05 "Chloe"

Raw Data:
```
0000000000000000001000000
000000000000000000000001000000
000000000003313233044A6F686E0542
726F776E0A313937302D30312D30320C
5068696C6164656C7068696105313930
31390331323405436 86C6F650542726F
776E04426C75650A313937302D30312D
30320C5068696C6164656C7068696105
31393032310331323305436 86C6F65
```

LEAF VALUE MAPPING 254B

Leaf ID	Offset	Last Leaf Value in Parent Obj.
0x01	0x0000	n/a
0x02	0x0004	n/a
0x03	0x0008	n/a
0x04	0x000C	n/a
0x05	0x0010	n/a
0x06	0x0014	n/a
0x07	0x0018	n/a
0x08	0x001C	n/a
0x09	0x0020	(no last leaf)
0x0A	0x0024	"123"
0x0B	**0x0029**	"John"
0x0C	**0x0029**	**"Brown"**
0x0D	0x002F	**"Brown"**
0x0E	0x003A	(no last leaf)
0x0F	0x0047	"Philadelphia"
0x10	0x004D	(no last leaf)
0x11	0x0051	"124"
0x12	0x0057	"Chloe"
0x13	0x005D	"Brown"
0x14	0x0062	"Blue"
0x15	0x006D	(no last leaf)
0x16	0x007A	"Philadelphia"
0x17	**0x0080**	(no last leaf)
0x18	**0x0080**	**"123"**
0x19	0x0084	**"123"**

Raw Data:
```
000000040008000C00100014
0018001C002000240029 0029
002F003A0047004D00510057
005D0062006D007A00800080
0084
```

FIG. 3E

(Compression friendly relative address leaf value dictionary)

LEAF VALUE COLLECTION 272

Offset	Leaf Value
[person ~ base 0x0000]	
0x0000	0x03 “123”
0x0004	0x04 “John”
0x0009	0x05 “Brown”
0x000F	0x05 “Brown”
0x0015	0x0A “1970-01-02”
[location ~ base 0x0020]	
0x0020	0x0C “Philadelphia”
0x002D	0x05 “19019”
[person ~ base 0x0033]	
0x0033	0x03 “124”
0x0037	0x05 “Chloe”
0x003D	0x05 “Brown”
0x0043	0x04 “Blue”
0x0048	0x0A “1970-01-02”
[location ~ base 0x0053]	
0x0053	0x0C “Philadelphia”
0x0060	0x05 “19021”
[pet ~ base 0x0066]	
0x0066	0x03 “123”
0x006A	0x03 “123”
0x006E	0x05 “Chloe”

Raw Data:

```
03313233044A6F686E0542726F776E05
42726F776E0A313937302D30312D3032
0C5068696C6164656C70686961053139
303139033132340543686C6F65054272
6F776E04426C75650A313937302D3031
2D30320C5068696C6164656C70686961
05313930323103313233033132330543
686C6F65
```

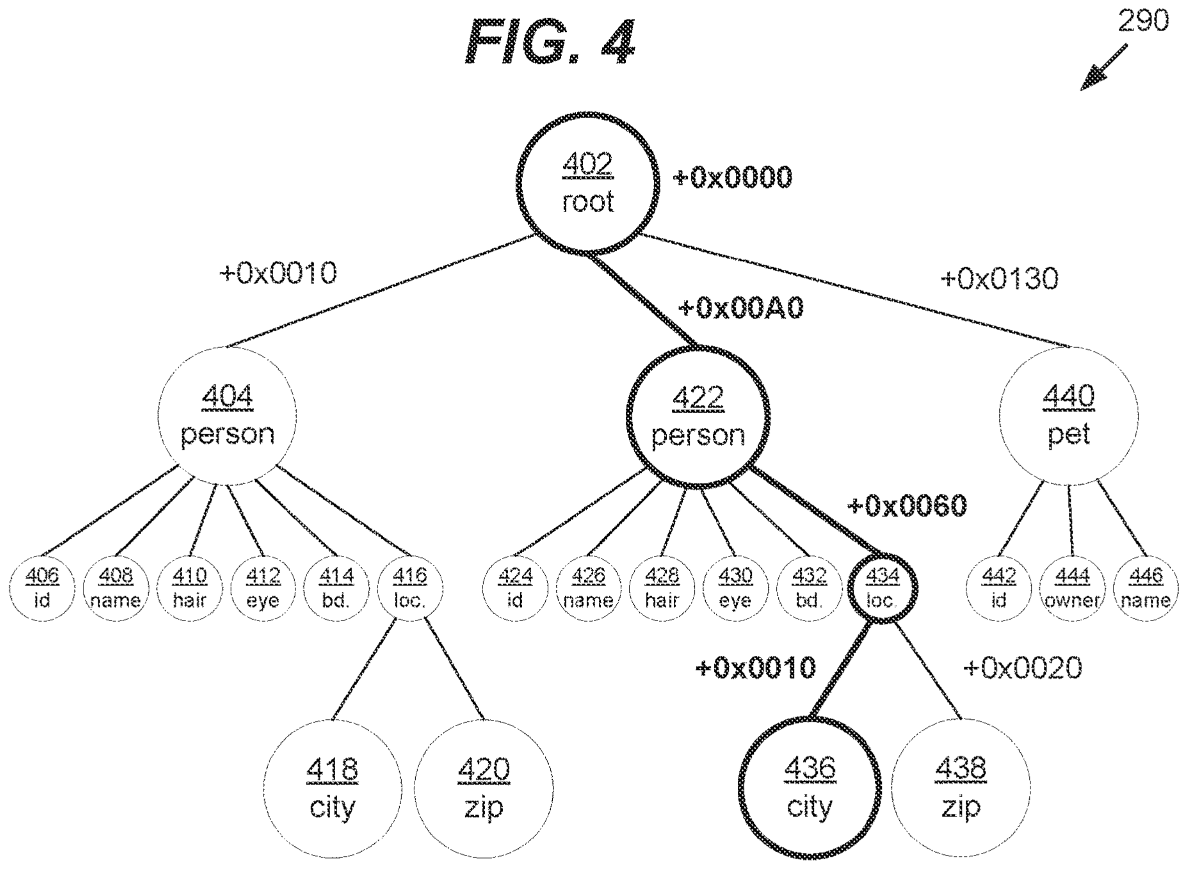
LEAF VALUE MAPPING 274

Leaf ID	Relative Offset
[person ~ base 0x0000]	
0x01	0x0000
0x02	0x0004
0x03	0x0009
0x04	0x000F
0x05	0x0015
[location ~ base 0x0020]	
0x06	0x0000
0x07	0x000D
[person ~ base 0x0033]	
0x08	0x0000
0x09	0x0004
0x0A	0x000A
0x0B	0x0010
0x0C	0x0015
[location ~ base 0x0053]	
0x0D	0x0000
0x0E	0x000D
[pet ~ base 0x0066]	
0x0F	0x0000
0x10	0x0004
0x11	0x0008

Raw Data:

```
000000040009000F00150000
000D00000004000A00100015
0000000D000000040008
```

FIG. 4



ABSOLUTE NODE JUMP OFFSETS 480

Node	Offset	Node	Offset
402	0x0000	426	0x00C0
404	0x0010	428	0x00D0
406	0x0020	430	0x00E0
408	0x0030	432	0x00F0
410	0x0040	434	0x0100
412	0x0050	**436**	**0x0110**
414	0x0060	438	0x0120
416	0x0070	440	0x0130
418	0x0080	442	0x0140
420	0x0090	444	0x0150
422	0x00A0	446	0x0160
424	0x00B0		

RELATIVE NODE JUMP OFFSETS 490

Node	Offset	Node	Offset
402	**0x0000**	426	0x0020
404	0x0010	428	0x0030
406	0x0010	430	0x0040
408	0x0020	432	0x0050
410	0x0030	**434**	**0x0060**
412	0x0040	**436**	**0x0010**
414	0x0050	438	0x0020
416	0x0060	440	0x0130
418	0x0010	442	0x0010
420	0x0020	444	0x0020
422	**0x00A0**	446	0x0030
424	0x0010		

TRAVERSAL 495

```
To Node 436:  402    -> 422    -> 434    -> 436
Offset Sums:  0x0000 + 0x00A0 + 0x0060 + 0x0010 = 0x0110
```

FIG. 5A

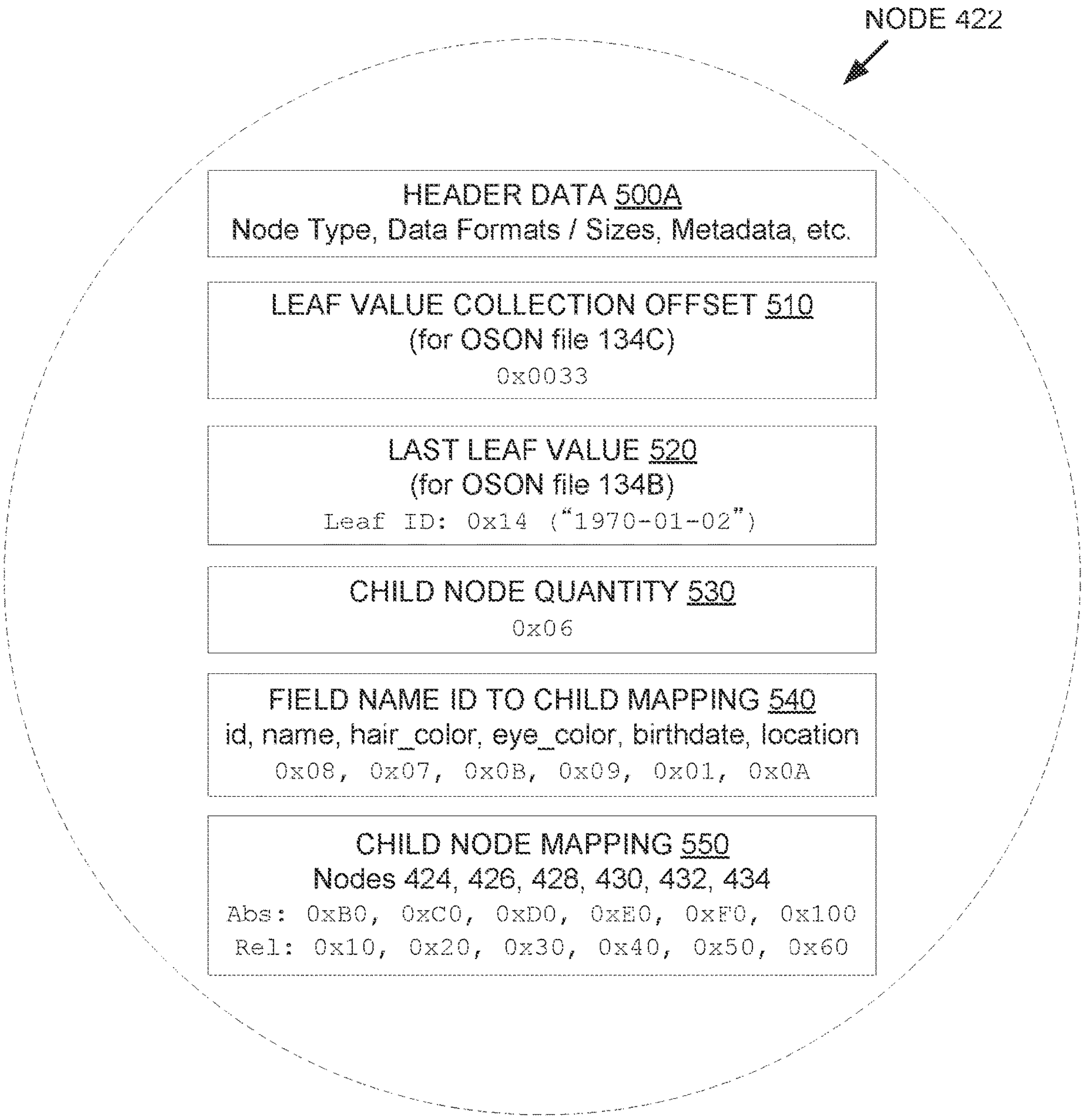
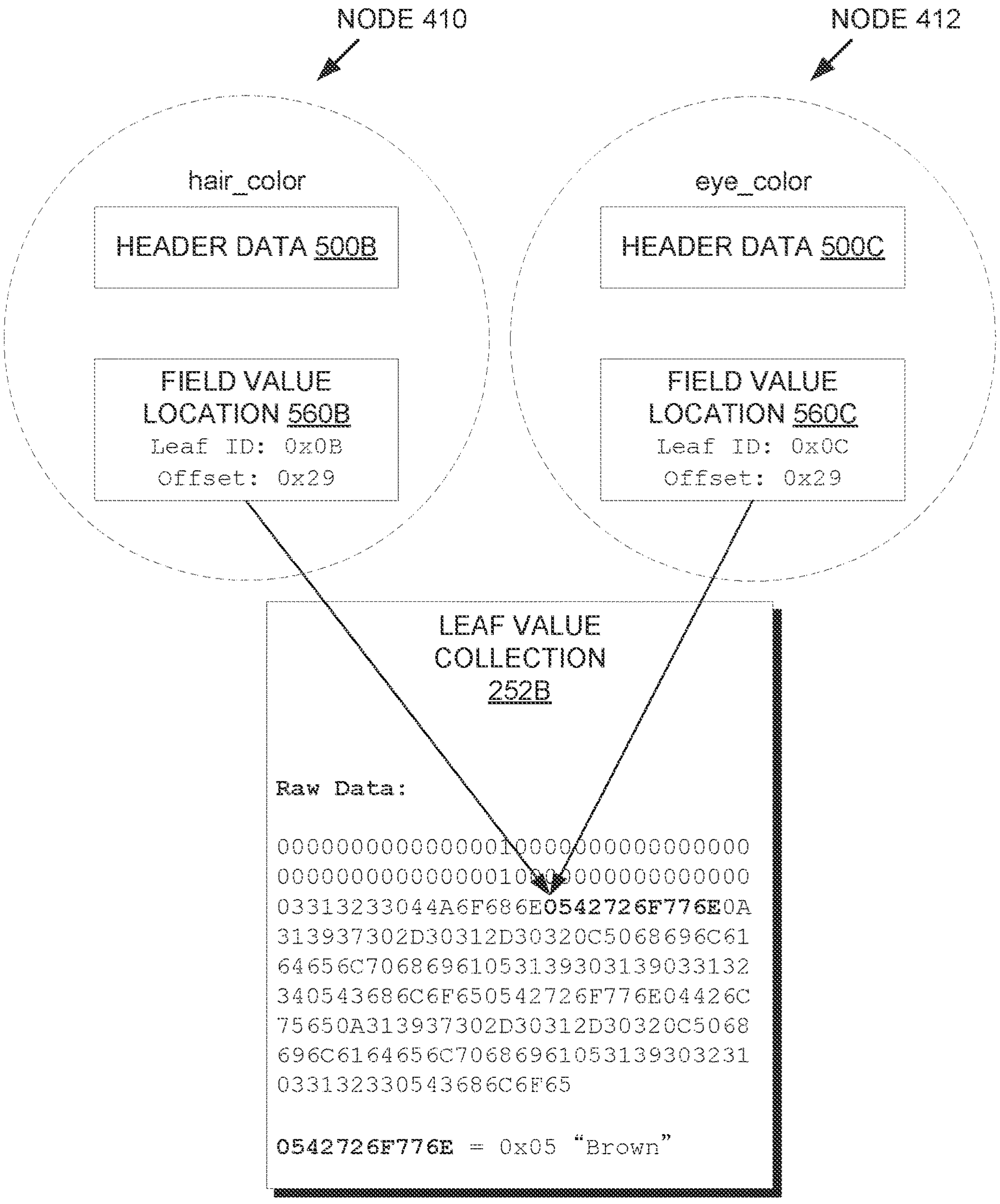

NODE 422
HEADER DATA 500A
Node Type, Data Formats / Sizes, Metadata, etc.
LEAF VALUE COLLECTION OFFSET 510
(for OSON file 134C)
0x0033
LAST LEAF VALUE 520
(for OSON file 134B)
Leaf ID: 0x14 ("1970-01-02")
CHILD NODE QUANTITY 530
0x06
FIELD NAME ID TO CHILD MAPPING 540
id, name, hair_color, eye_color, birthdate, location
0x08, 0x07, 0x0B, 0x09, 0x01, 0x0A
CHILD NODE MAPPING 550
Nodes 424, 426, 428, 430, 432, 434
Abs: 0xB0, 0xC0, 0xD0, 0xE0, 0xF0, 0x100
Rel: 0x10, 0x20, 0x30, 0x40, 0x50, 0x60

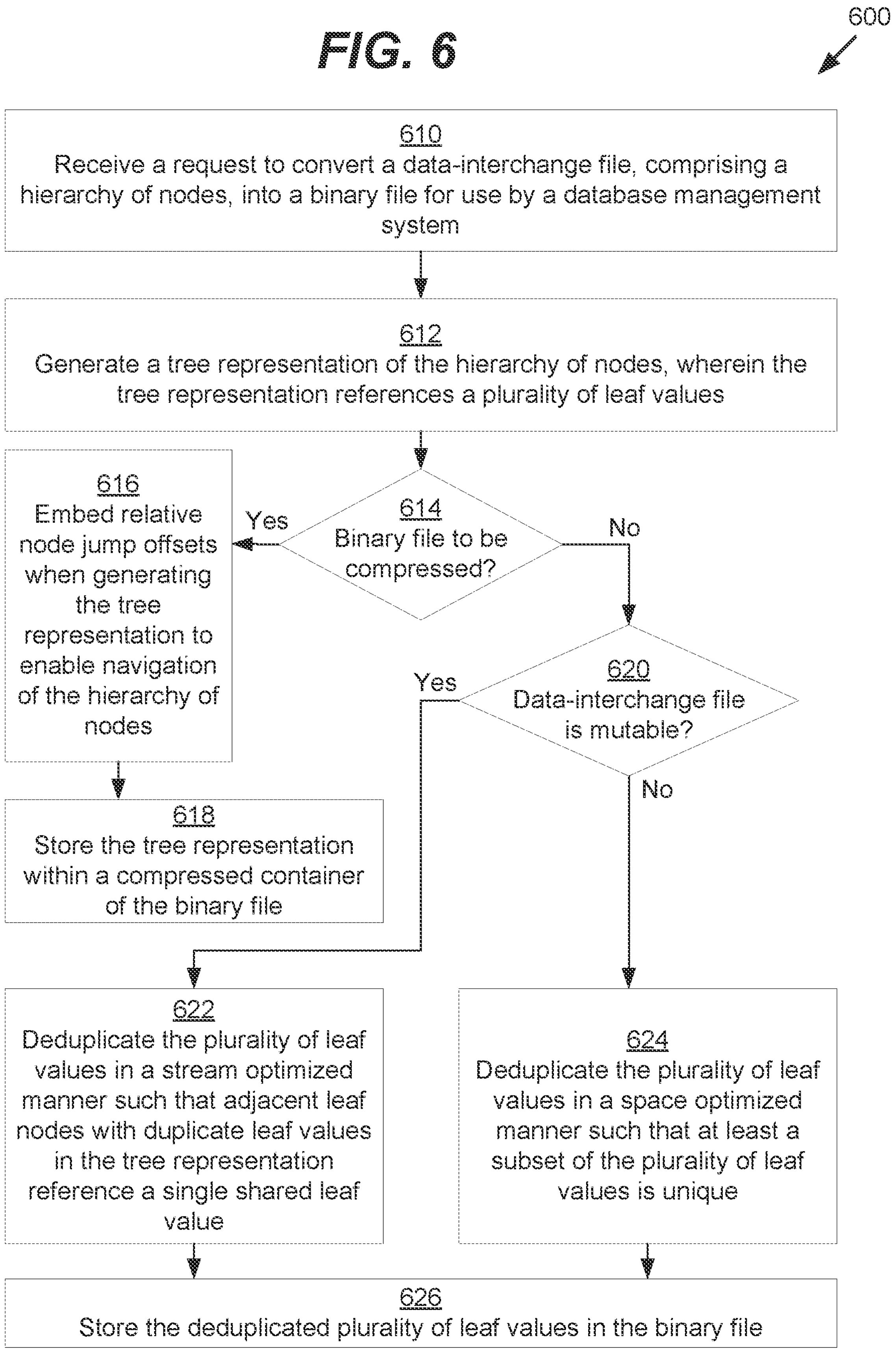
FIG. 5B



```
00000000000000010000000000000000
00000000000000001000000000000000
03313233044A6F686E0542726F776E0A
313937302D30312D30320C5068696C61
64656C706869610531393031390331 32
340543686C6F650542726F776E04426C
75650A313937302D30312D30320C5068
696C6164656C70686961053139303231
03313233054368 6C6F65

0542726F776E = 0x05 “Brown”
```

FIG. 6



600
610
Receive a request to convert a data-interchange file, comprising a hierarchy of nodes, into a binary file for use by a database management system
612
Generate a tree representation of the hierarchy of nodes, wherein the tree representation references a plurality of leaf values
614
Binary file to be compressed?
Yes
No
616
Embed relative node jump offsets when generating the tree representation to enable navigation of the hierarchy of nodes
618
Store the tree representation within a compressed container of the binary file
620
Data-interchange file is mutable?
Yes
No
622
Deduplicate the plurality of leaf values in a stream optimized manner such that adjacent leaf nodes with duplicate leaf values in the tree representation reference a single shared leaf value
624
Deduplicate the plurality of leaf values in a space optimized manner such that at least a subset of the plurality of leaf values is unique
626
Store the deduplicated plurality of leaf values in the binary file

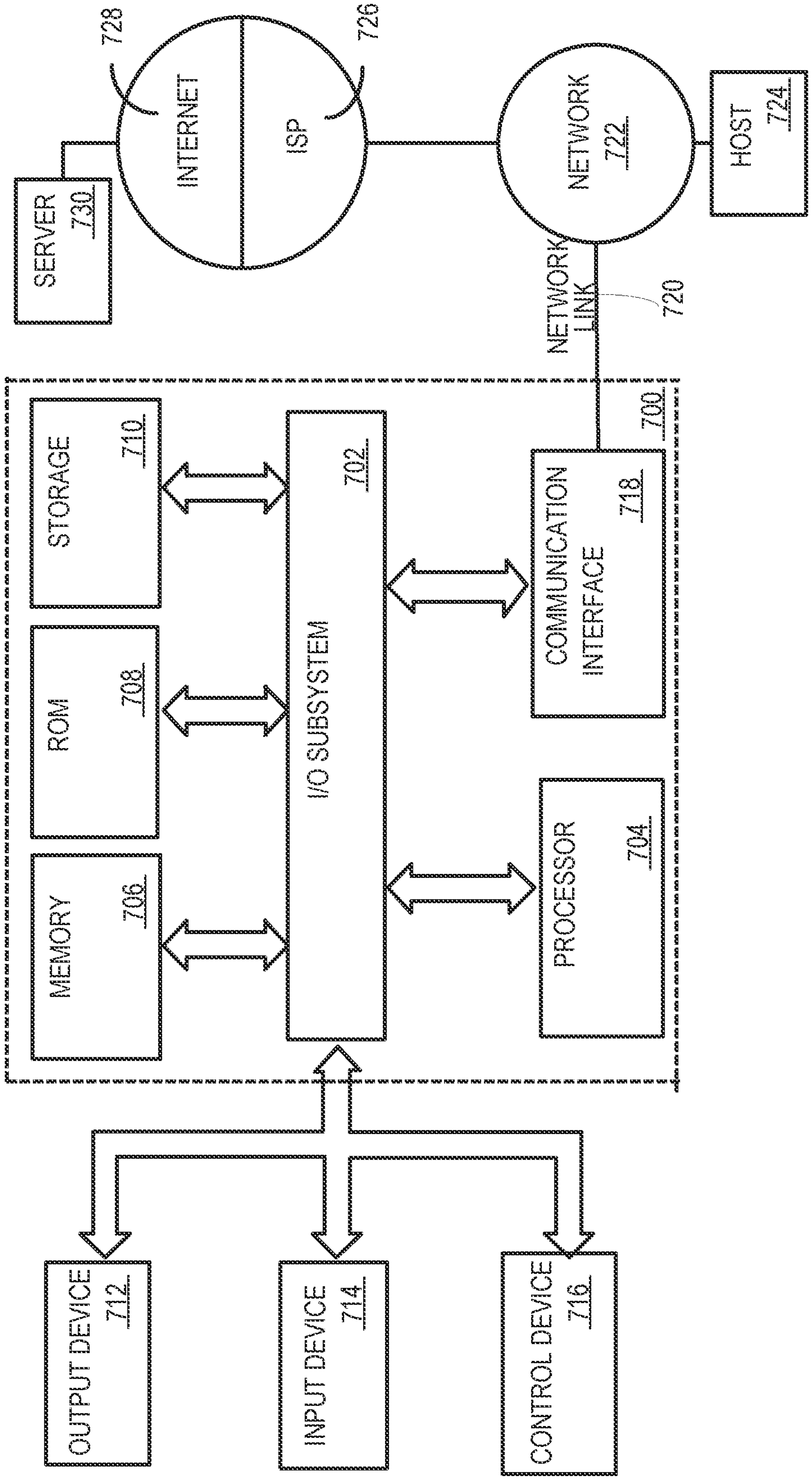

SERVER 730
INTERNET
728
ISP
726
NETWORK 722
HOST 724
NETWORK LINK
720
STORAGE 710
ROM 708
MEMORY 706
I/O SUBSYSTEM
702
700
COMMUNICATION INTERFACE 718
PROCESSOR 704
OUTPUT DEVICE 712
INPUT DEVICE 714
CONTROL DEVICE 716

FIG. 7

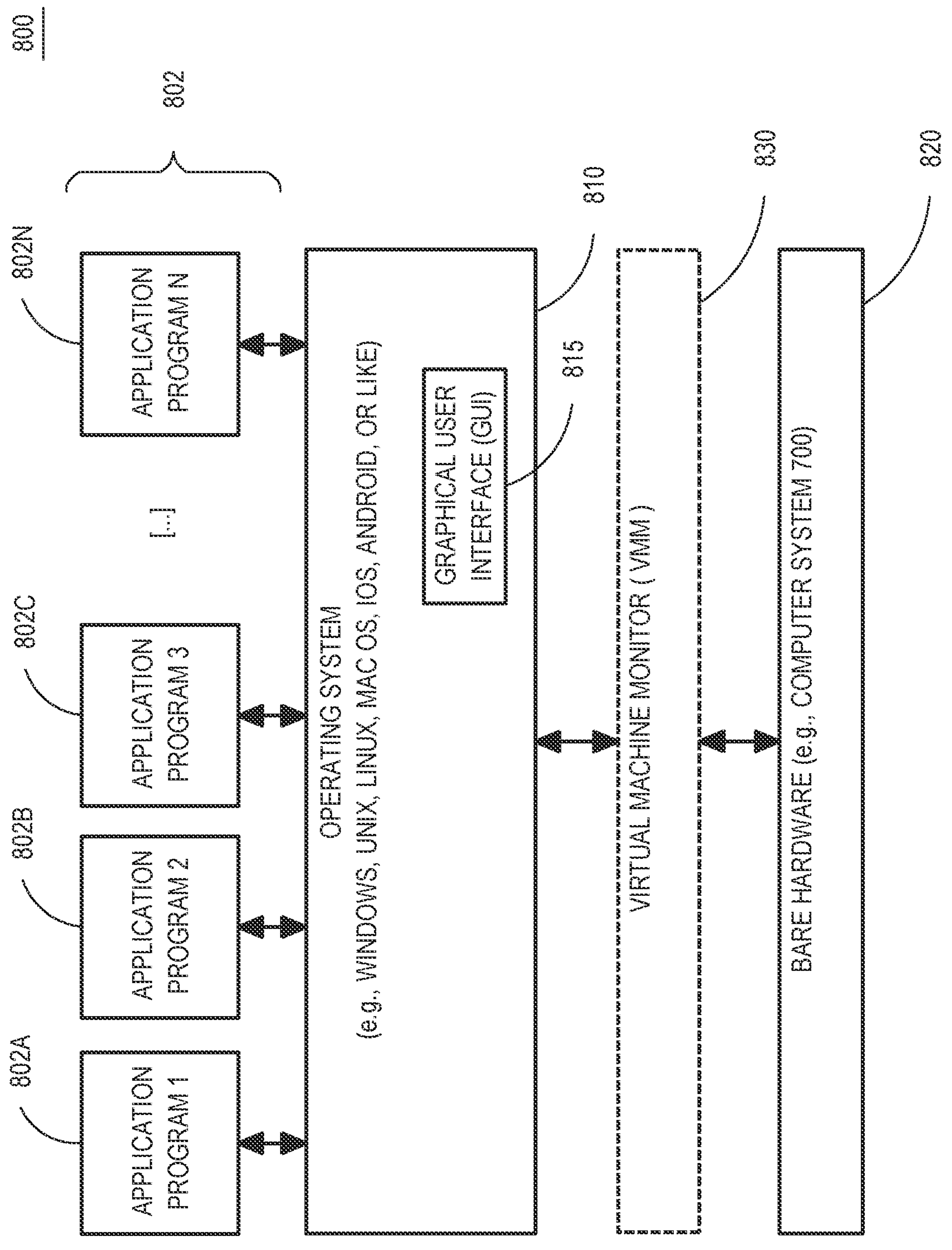

800
802
802A
APPLICATION PROGRAM 1
802B
APPLICATION PROGRAM 2
802C
APPLICATION PROGRAM 3
[...]
802N
APPLICATION PROGRAM N
810
OPERATING SYSTEM (e.g., WINDOWS, UNIX, LINUX, MAC OS, IOS, ANDROID, OR LIKE)
815
GRAPHICAL USER INTERFACE (GUI)
830
VIRTUAL MACHINE MONITOR (VMM)
820
BARE HARDWARE (e.g., COMPUTER SYSTEM 700)

FIG. 8

TECHNIQUE OF REDUCING SIZE OF BINARY JSON WITH/WITHOUT COMPRESSION

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to U.S. patent application Ser. No. 14/836,680, titled "Techniques Related to Binary Encoding of Hierarchical Data Objects to Support Efficient Path Navigation of the Hierarchical Data Objects", filed Aug. 26, 2015, the entire contents of which is hereby incorporated by reference as if fully set forth herein.

FIELD OF THE INVENTION

Embodiments of the present invention relate to converting text format data-interchange files, such as JavaScript Object Notation (JSON) files, into size efficient binary representations. More particularly, embodiments of the present invention relate to techniques to convert JSON files into Oracle binary JSON (OSON) files with reduced file sizes in both compressed and uncompressed formats while supporting high performance for query processing and partial updates.

BACKGROUND

JavaScript Object Notation (JSON) is an open standard file format and data interchange format that uses human-readable text to store and transmit data objects consisting of attribute-value pairs and arrays. JSON is a language-independent data format developed in the early 2000s. Internet Engineering Task Force (IETF) Request for Comments (RFC) 4627 provides further detail and specifies that JSON can represent four primitive types (strings, numbers, Booleans and null) and two structured types (objects and arrays).

JSON files are frequently used in database environments, such as relational database and graph database environments. When JSON files are used in database environments, the JSON files can become large and consume excessive storage space and/or be inefficient to search. Other shortcomings may also exist with respect to the use of JSON files in database environments.

While JSON files can be converted into binary representations for more efficient usage in database environments, existing approaches may suffer from several drawbacks. For example, Binary JSON (BSON), as used by MongoDB, is a binary representation that is a serialization of JSON text into binary data. However, since this serialization lacks any metadata structures for navigation, traversal and partial updates to the BSON may require parsing the entire BSON file, a computationally expensive process. Additionally, the BSON file may still require significant storage space in proportion to the original JSON file. While general purpose compression algorithms may be applied to the BSON file to reduce storage footprint, this also necessitates a decompression of the entire BSON file prior to any database operations, precluding efficient random access and updates.

Any approaches described in this section are approaches that could be pursued, but not necessarily approaches that have been previously conceived or pursued. Therefore, unless otherwise indicated, it should not be assumed that any of the approaches described in this section qualify as prior art merely by virtue of their inclusion in this section.

BRIEF DESCRIPTION OF THE DRAWINGS

The example embodiment(s) of the present invention are illustrated by way of example, and not in way by limitation, in the figures of the accompanying drawings and in which like reference numerals refer to similar elements and in which:

FIG. **1**A is a block diagram that depicts an example network arrangement for a database management system (DBMS) in which a conversion of a JSON file into an Oracle binary JSON (OSON) file may be supported.

FIG. **1**B is a listing of an example JSON file.

FIG. **2** depicts data structures within example OSON files.

FIG. **3**A depicts example data structures for a field name dictionary of an OSON file.

FIG. **3**B depicts example space optimized deduplicated leaf values of an OSON file.

FIG. **3**C depicts example default dictionary reservations for common leaf values.

FIG. **3**D depicts example stream optimized deduplicated leaf values of an OSON file.

FIG. **3**E depicts an example compression friendly relative address leaf value dictionary of an OSON file.

FIG. **4** depicts an example tree representing a hierarchy of nodes from a JSON file, absolute and relative node jump offset tables for the tree, and an example traversal of the tree using relative offsets.

FIG. **5**A depicts example data structures within a parent node of a tree.

FIG. **5**B depicts example data structures within adjacent leaf nodes of a tree.

FIG. **6** is a flow diagram that depicts an example process that a computing device may perform to convert a JSON file into an OSON file.

FIG. **7** illustrates a block diagram of a computing device in which the example embodiment(s) of the present invention may be embodiment.

FIG. **8** illustrates a block diagram of a basic software system for controlling the operation of a computing device.

DETAILED DESCRIPTION

In the following description, for the purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the present invention. It will be apparent, however, that the present invention may be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to avoid unnecessarily obscuring the present invention.

GENERAL OVERVIEW

Data structures and methods are described for converting a text format data-interchange file, such as JavaScript Object Notation (JSON) file, into size efficient binary representations, referred to herein as Oracle binary JSON (OSON). OSON is an open format that is provided to the public and is available from Oracle Corporation of Austin, Texas, USA.

When the OSON file is to be compressed, a tree representation of the JSON file is built with compression friendly relative node jump offsets instead of absolute node jump offsets. Additionally, relative offsets may also be used for leaf value mappings. Higher compression ratios are thereby attainable, as relative offsets have less entropy than absolute offsets. Deduplication of field names and leaf values may also be omitted when the OSON file is to be compressed, as the compression can perform a similar size reduction as the deduplication.

When the OSON file is to be uncompressed, a determination is made wither the JSON file is mutable or immutable (read-only). When the JSON file is mutable, then the leaf values to be stored in the OSON file are deduplicated in a stream optimized manner. For example, the last leaf value for each parent node can be tracked. When a leaf node to be processed has a leaf value that matches the last leaf value, then the adjacent leaves with the same parent node can reference a shared leaf value that is deduplicated, or stored once in the OSON file. This stream optimized deduplication can be implemented with minimal overhead, thereby preserving database query and update performance.

When the JSON file is immutable (read-only), then the leaf values to be stored in the OSON file are deduplicated in a space optimized manner. For example, the entire JSON file may be analyzed and at least a subset of the leaf values can be made unique during the deduplication. The subset can correspond to each of the leaf values in the JSON file, or to leaf values that do not exceed a threshold size. While performing this space optimized deduplication incurs a one-time processing penalty, this may be offset by reducing storage footprint and accelerating multiple future database reads.

Accordingly, a size efficient OSON format is provided for JSON. When the OSON is to be compressed, the offsets are stored as relative offsets to reduce entropy for facilitated compression. When the OSON is to be uncompressed, the leaf values are deduplicated using a space optimized or stream optimized manner depending on whether the JSON is mutable or immutable. In this manner, the OSON file size may be reduced in both compressed or uncompressed formats while maintaining high performance for database queries and partial updates.

Network Arrangement Architecture

FIG. **1**A is a block diagram that depicts an example network arrangement **100** for a database management system **110** in which a conversion of text JSON file **142** into OSON file **134** may be supported, according to one or more embodiments. Network arrangement **100** includes a client device **140** and a database management system **110** communicatively coupled via a network **150**. Network **150** may be implemented with any type of medium and/or mechanism that facilitates the exchange of information between client device **140** and database management system **110**. Network arrangement **100** may include other devices, including client devices, server devices, storage devices, and display devices, according to one or more embodiments.

Client device **140** may be implemented by any type of computing device that is communicatively connected to network **150**. In network arrangement **100**, client device **140** is configured with a database client, which may be implemented in any number of ways, including as a stand-alone application running on client device **140**, or as a plugin to a browser running at client device **140**, etc. Client device **140** may submit one or more database queries and/or database administration commands to database management system **110**. For example, client device **140** may request text JSON file **142** or binary JSON file **144** to be loaded, converted, and stored as OSON file **134**. Client device **140** may be configured with other mechanisms, processes and functionalities, depending upon a particular implementation.

In network arrangement **100**, database management system **110** includes one or more server nodes, such as database server computing device **120**. Database server computing device **120** is implemented by any type of computing device that is capable of communicating with client device **140** over network **150**.

Database server computing device **120** maintains access to and manages data in database **132** (i.e., on storage **130**).

According to one or more embodiments, access to a given database comprises access to (a) a set of disk drives storing data for the database, and (b) data blocks stored thereon. Database **132** may reside in any type of storage **130**, including volatile and non-volatile storage, e.g., random access memory (RAM), one or more hard disks, main memory, etc.

Database server computing device **120** includes JSON to OSON converter **160**. For example, client device **140** may issue an administrative command to database management system **110** to request conversion of text JSON file **142** or binary JSON file **144** into OSON file **134**. JSON to OSON converter **160** may determine whether OSON file **134** is to be uncompressed to compressed and utilizes uncompressed converter **170** or compressed converter **180**, respectively, to generate OSON file **134** from the requested input, e.g. text JSON file **142**.

Uncompressed converter **170** utilizes mutable JSON detector **172** to determine whether the input JSON is mutable or immutable and utilizes stream optimized leaf value deduplicator **174** or space optimized leaf value deduplicator **176**, respectively, to deduplicate the leaf values to be stored in OSON file **134**. Space optimized leaf value deduplicator **176** may optionally utilize size filter **178** to skip deduplication of leaf values above a threshold size. When compared to space optimized leaf value deduplicator **176**, stream optimized leaf value deduplicator **174** may configure OSON file **134** to support higher DBMS performance for partial updates in exchange for greater storage requirements.

Compressed converter **180** utilizes relative offset generator **182** to embed relative jump offsets for various data structures to be stored in OSON file **134**, such as leaf value mappings and tree node navigation structures. Since relative jump offsets have less data entropy than absolute jump offsets, data compressor **184** can achieve a higher compression ratio when compressing the data embedded by relative offset generator **182**. Thus, regardless of whether OSON file **134** is uncompressed or compressed, a storage footprint of OSON file **134** can be reduced.

Any of the functionality attributed to database management system **110** herein may be performed by any other entity, which may or may not be depicted in network arrangement **100**, according to one or more embodiments. For example, in some embodiments, JSON to OSON converter **160** may instead be implemented on client device **140**. Database server computing device **120** may also be configured with other mechanisms, processes and functionalities, depending upon a particular implementation.

In an embodiment, each of the processes and/or functionality described in connection with database management system **110**, database server computing device **120** and/or database **132** are performed automatically and may be implemented using one or more computer programs, other software elements, and/or digital logic in any of a general-purpose computer or a special-purpose computer, while performing data retrieval, transformation, and storage operations that involve interacting with and transforming the physical state of memory of the computer.

JSON File Listing

FIG. **1**B is a listing of an example text JSON file **142**. Binary JSON file **144** may contain contents similar to text JSON file **142**, but serialized as binary data. When JSON to OSON converter **160** receives a request to convert binary JSON file **144** to OSON, binary JSON file **144** may be first converted to a text JSON representation for processing, or alternatively a plug-in or specialized binary converter may be used to efficiently convert the binary format to OSON.

For illustrative purposes, the examples described herein will focus on text JSON to OSON conversion.

As shown in FIG. **1**B, text JSON file **142** provides a hierarchy of nodes including two "person" objects and one "pet" object, each with various child nodes. Parsing of text JSON file **142** naturally follows a depth first traversal. In some embodiments, text JSON file **142** may be immutable or read-only, such as by including blocks of a blockchain or other immutable data, which are detectable by mutable JSON detector **172**. In other embodiments, a conversion request to JSON to OSON converter **160** may explicitly specify that text JSON file **142** is to be treated as read-only.

OSON Files

FIG. **2** depicts data structures within example OSON file **134**A, OSON file **134**B, and OSON file **134**C. OSON file **134**A may be generated via space optimized leaf value deduplicator **176**. OSON file **134**B may be generated via stream optimized leaf value deduplicator **174**. OSON file **134**C may be generated via compressed converter **180**.

Each OSON file **134**A-**134**C includes tree **290**, which may correspond to a tree representation of the hierarchy of nodes shown in text JSON file **142**. Each OSON file **134**A-**134**C also includes a respective field name dictionary **210**A-**210**C, which define the field names from text JSON file **142**. Each OSON file **134**A-**134**C also includes a leaf dictionary, which may include leaf value collections, leaf value mappings, and optional leaf hash mappings. The leaf dictionaries of OSON files **134**A-**134**B may be reduced in size via deduplication. The leaf dictionary of OSON file **134**C may be reduced in size via compression instead of deduplication.

OSON file **134**A may correspond to a conversion from text JSON file **142** as immutable JSON. Accordingly, space optimized leaf value deduplicator **176** may be utilized to generate space optimized leaf deduplication **230**, which includes leaf value collection **232**, leaf value mapping **234**, and leaf hash mapping **236**. Leaf value collection **232** may correspond to a collection of leaf values that have been deduplicated in a space optimized manner. Leaf value mapping **234** may be a data structure that maps identifiers to offsets within leaf value collection **232**. Leaf hash mapping **236** may be a lookup data structure, such as a hash table, that associates leaf value mapping **234** to associated lookup values, such as hash values. The combination of data structures in space optimized leaf deduplication **230** allows database management system **110** to quickly encode and identify objects from text JSON file **142**.

OSON file **134**B may correspond to a conversion from text JSON file **142** as mutable JSON. Accordingly, stream optimized leaf value deduplicator **174** may be utilized to generate stream optimized leaf deduplication **250**, which includes leaf value collection **252**B and leaf value mapping **254**B. Leaf value collection **252**B and leaf value mapping **254**B may include default initial values for commonly encountered values, with appended user defined leaf values as they are encountered in text JSON file **142**. To provide a lightweight deduplication that incurs minimal overhead, the appended user defined leaf values may be deduplicated when adjacent leaf nodes of a parent node have identical values, rather than attempting to deduplicate all leaf values. Since matching to previous leaf values is not as critical in this stream optimized deduplication, a lookup data structure similar to leaf hash mapping **236** may be omitted from stream optimized leaf deduplication **250**.

OSON file **134**C may correspond to a conversion from text JSON file **142** that is intended to be compressed. Accordingly, the data of OSON file **134**C may be placed in compressed container **260**, which includes field name dictionary **210**C, leaf value collection **272**, leaf value mapping **274**, and tree **290**. Compressed container **260** may use any compression algorithm and may be optionally encrypted. To reduce data entropy and enable a higher compression ratio for compressed container **260**, relative offset generator **182** may be used to configure one or more data structures, such as leaf value mapping **274** and tree **290**, to use relative offset format **280** instead of absolute offsets.

Field Name Dictionary

FIG. **3**A depicts example data structures for field name dictionary **210**A-**210**C of respective OSON file **134**A-**134**C. Table **300** includes field name identifiers **302**, field names **304**, hash codes **306**, and truncated hash codes **308**. Table **300** may be built in a manner similar to table **200** as described in FIG. **2** and related text of U.S. patent application Ser. No. 14/836,680.

For example, JSON to OSON converter **160** may parse field names **304** from text JSON file **142** and generate hash codes **306** using any hash function, such as Message-Digest Algorithm (MD5) or Secure Hash Algorithm 1 (SHA-1). Note that in the Figures, only the most significant 32 bits of each hash code are shown for simplicity. To reduce storage requirements, the hash codes **306** may be further shortened to truncated hash codes **308** using any modulo or mask function, such as by masking to select only the most significant byte, as shown. As described in U.S. patent application Ser. No. 14/836,680, hash code collisions can be resolved by comparing string lengths or string values. Truncated hash codes **308** may be sorted in any order, e.g. ascending numeric order, to assign field name identifiers **302** to field names **304** using e.g. incremental integer values. While table **300** is configured as a hash table, any lookup data structure can be utilized.

Field name collection **212** may be built as text JSON file **142** is parsed. Each field name in field name collection **212** can be written as it is encountered in text JSON file **142**. For example, the first encountered field name is "person", which is 6 bytes long, and thus is prefaced with "0x06" as a length indicator. The field name entries can be concatenated together to form the raw data as shown. While the offsets are shown for clarity, it should be understood that the raw data of field name collection **212** does not include the offsets, which are instead indicated by field name mapping **214**.

It can be observed that duplicate entries can be omitted in field name collection **212**. For example, the field name "person" appears twice in text JSON file **142**, but is only stored once in field name collection **212**. By performing a lookup in table **300** prior to writing a field name, field names that have already been previously written can be detected, and thus duplicate entries for field name collection **212** can be omitted.

As shown in field name collection **212**, each entry includes a single byte length indicator and a string of single byte American Standard Code for Information Interchange (ASCII) characters. However, other encoding methods are possible, such as null terminated strings and multi-byte character encodings such as Unicode.

Field name mapping **214** may map field name identifiers **302** to offsets within field name collection **212**. For example, for field ID 0x0001, the offset is given as "0x0024", which means that the string 0x09 "birthdate" is located at offset 0x0024 in field name collection **212**. As shown in the raw data, only the offsets are stored, as the field ID can be inferred by the position of the entries in field name mapping **214**.

Field hash mapping **216** maps field name identifiers **302** to truncated hash codes **308**. For example, field ID 0x01 is mapped to truncated hash code "0x1B". Similar to field name mapping **214**, the field ID can be inferred by position in the raw data and may thus be omitted.

As shown by field name dictionary **210**A, the combination of field name collection **212**, field name mapping **214**, and field hash mapping **216** can be used to recreate table **300**. In cases where a lookup data structure such as a hash table is optional, field hash mapping **216** may be omitted, as shown in field name dictionary **210**B. In this case, field name collection **212** and field name mapping **214** may be a straightforward serialization of field names that may include duplicate values. Similarly, field name dictionary **210**C may also be a straightforward serialization of field names since compressed container **260** can provide file size reduction.

While string length indicators, field name identifiers **302**, and truncated hash codes **308** are shown to occupy a single byte and offsets of field name mapping **214** are shown to occupy two bytes, the sizing of the data structures shown in the Figures are exemplary and can be sized and resized according to anticipated workload and data set size.

Space Optimized Deduplicated Leaf Dictionary

FIG. **3**B depicts example space optimized leaf deduplication **230** of OSON file **134**A. Table **320** includes leaf value identifiers **322**, leaf values **324**, hash codes **326**, and truncated hash codes **328**. Table **320** may be generated in a manner similar to table **300** of FIG. **3**A, but by parsing leaf values instead of field names in text JSON file **142**. Space optimized deduplication **230** may also be created in a manner similar to field name dictionary **210**A, wherein space optimized deduplication **230** includes leaf value collection **232**, leaf value mapping **234**, and leaf hash mapping **236**.

As shown in leaf value collection **232**, the leaf values may be deduplicated such that each of the leaf values is unique. Thus, the deduplication is space optimized. In some embodiments, size filter **178** may be utilized to skip deduplication of leaf values that exceed a size threshold. In this case, only a subset of the leaf values may be unique. Further, while space optimized leaf deduplication **230** is demonstrated using scalar leaf values, it should be understood that the deduplication techniques described herein can also be applied to other value collections, such as JSON array objects or nested JSON objects.

Example Default Dictionary Reservations for Common Leaf Values

FIG. **3**C depicts example default dictionary reservations for common leaf values. Table **340** may be structured similar to table **320** and includes leaf value identifiers **342**, leaf values **344**, hash codes **346**, and truncated hash codes **348**. As shown in table **340**, leaf values **344** are prepopulated with reserved scalar values that are likely to be commonly encountered when parsing JSON files. Thus, prior to reading any leaf values from text JSON file **142**, stream optimized leaf value deduplicator **174** may prepopulate leaf values **344** with null, true, false, empty string, 0, 1, empty object, and empty array. These values are exemplary and any set of default values may be used. When text JSON file **142** is known to be mutable, these default entries will be helpful to accelerate initial parsing and any future partial updates.

As shown in FIG. **3**C, the lookup data structure, or hash table portion, may be optional. For example, to accelerate stream processing, hashes of incoming JSON leaf values may be omitted in stream optimized leaf deduplication **250**. Since the number of reserved dictionary entries in table **340** may be limited in quantity, or eight (8) entries in the example shown in FIG. **3**C, a lookup data structure may be unnecessary to quickly resolve leaf value identifiers of common leaf values. Thus, stream optimized leaf value deduplicator **174** may begin by generating leaf value collection **252**A and leaf value mapping **254**A prior to parsing text JSON file **142**, as indicated by the empty user data areas.

Stream Optimized Deduplicated Leaf Dictionary

FIG. **3**D depicts example stream optimized leaf deduplication **250** of OSON file **134**B. After parsing text JSON file **142**, stream optimized leaf value deduplicator **174** may populate the user data areas of leaf value collection **252**A and leaf value mapping **254**A to generate leaf value collection **252**B and leaf value mapping **254**B, respectively, which are both contained in stream optimized leaf deduplication **250**.

As shown in leaf value collection **252**B, leaf values may be written as encountered in text JSON file **142**, with the exception that adjacent identical leaf values may be mapped to a single shared leaf value within a parent node. This is indicated for leaf value ID 0B, or "Brown" in a "person" parent object, and leaf value ID **16**, or "123" in a "pet" parent object. Referring to leaf value mapping **254**B, it can be observed that leaf ID 0x0B and 0x0C both refer to offset 0x0029, or leaf value ID 0B, and leaf ID 0x17 and 0x18 both refer to offset 0x0080, or leaf value ID **16**. This type of deduplication may be especially effective for unstructured lists and arrays where duplicate values are often repeated.

While leaf value collection **252**B is not deduplicated as aggressively as leaf value collection **232**, stream optimized leaf value deduplicator **174** can generate leaf value collection **252**B with minimal overhead since leaf values only need to be compared to a prior leaf value maintained for each parent node, as illustrated by the "Last Leaf Value in Parent Obj." column in leaf value mapping **254**B. Since maintenance of a hash table or other lookup data structure can be avoided, stream optimized leaf value deduplicator **174** can still reduce the file size of OSON file **134**B while incurring minimal performance impacts.

Compression Friendly Leaf Value Dictionary

FIG. **3**E depicts an example compression friendly relative address leaf value dictionary of OSON file **134**C. As shown in leaf value collection **272**, the leaf values can be written as they are read from text JSON file **142** without attempting any deduplication. Optionally, leaf value mapping **274** may be written using relative offsets instead of absolute offsets. Thus, as shown in leaf value mapping **274**, each offset is relative to its parent object. In this manner, the entropy of leaf value mapping **274** can be reduced, allowing a higher compression ratio to be achieved for compressed container **260**. As shown by the inclusion of tree **290** in relative offset format **280**, tree **290** may also utilize relative offsets for node navigation to achieve a higher compression ratio, as shown in more detail in conjunction with FIG. **4** below.

Tree Representation of Json Nodes

FIG. **4** depicts an example tree **290** representing a hierarchy of nodes from text JSON file **142**, absolute node jump offsets **480** and relative node jump offsets **490** for tree **290**, and an example traversal **495** of tree **290** using relative offsets. Tree **290** includes node **402**, node **404**, node **406**, node **408**, node **410**, node **412**, node **414**, node **416**, node **418**, node **420**, node **422**, node **424**, node **426**, node **428**, node **430**, node **432**, node **434**, node **436**, node **438**, node **440**, node **442**, node **444**, and node **446**. Tree **290** may be built in a manner similar to hierarchical tree of nodes **400** as described in FIG. **4** and related text of U.S. patent application Ser. No. 14/836,680.

For purposes of illustration, it may be assumed that each of nodes **402**-**446** occupies 0x10 bytes, although each node may actually occupy a variable size depending on the node type, number of child nodes, etc. As shown in absolute node jump offsets **480**, nodes **402**-**446** are concatenated together in tree **290** according to a parsing order of nodes from text JSON file **142**. Absolute node jump offsets **480** may be embedded in nodes **402**-**446** of tree **290**, for example by including jump offsets to child nodes in each parent node.

To provide a compression friendly form of tree **290**, relative node jump offsets **490** may be embedded instead of absolute node jump offsets **480**. In this case, a current offset may be maintained while traversing tree **290**. For example, a query may be issued to retrieve a city where the person "Chloe" lives. Database management system **110** may generate a corresponding traversal **495** to retrieve the requested data to answer the query. To find the node for the city where Chloe lives, or node **436**, the relative offsets for each node in traversal **495** may be added together, or node **402**+node **422**+node **434**+node **436**=0x0000+0x00A0+0x0060+0x0010=0x0110. This matches the offset of node **436**=0x0110 in absolute node jump offsets **480**.

Relative node jump offsets **490** can be compressed with a higher compression ratio since it has less data entropy than absolute node jump offsets **480**. For example, it can be seen that the offset "0x0010" appears several times in relative node jump offsets **490**, whereas it appears only once in absolute node jump offsets **480**. Thus, by using relative offset format **280** for tree **290** in OSON file **134**C, a higher compression ratio can be achieved for compressed container **260**.

Parent Node in Tree Representation

FIG. **5**A depicts example data structures within node **422** of tree **290**. Node **422** includes header data **500**A, leaf value collection offset **510**, last leaf value **520**, child node quantity **530**, field name ID to child mapping **540**, and child node mapping **550**. The data structures of node **422** may be similar to those shown in node **404** as described in FIG. **5** and related text of U.S. patent application Ser. No. 14/836,680, but augmented with some new data structures including leaf value collection offset **510** and last leaf value **520**.

As shown in FIG. **5**A, node **422** of this application may share several fields with node **404** of U.S. patent application Ser. No. 14/836,680. Header data **500**A may include metadata such as node type, data format and data size definitions, etc. Child node quantity **530** identifies a number of child nodes connected to node **422**. Field name ID to child mapping **540** identifies the field names of the child nodes connected to node **422**, as defined by field name mapping **214** and field name collection **212**.

Leaf value collection offset **510** may define an offset of node **422** (person-base 0x0033) within leaf value collection **272**, thereby allowing the relative offsets of leaf value mapping **274** to be utilized. Leaf value collection offset **510** may be present when node **422** is stored in tree **290** in relative offset format **280** within compressed container **260** of OSON file **134**C.

Last leaf value **520** identifies the value of the last leaf in parent node **422**, or leaf ID 0x014="1970-01-02". Last leaf value **520** may be present when node **422** is stored in tree **290** of OSON file **134**B, which includes stream optimized leaf deduplication **250**.

Child node mapping **550** defines the child nodes connected to node **422**, or nodes **424**, **426**, **428**, **430**, **432**, and **434**. Absolute offsets to the child nodes may be used when node **422** is stored uncompressed in tree **290** of OSON file **134**A and **134**B, whereas relative offsets to the child nodes

may be used when node **422** is stored in tree **290** in relative offset format **280** within compressed container **260** of OSON file **134**C.

Leaf Nodes Referencing Shared Value in Tree Representation

FIG. **5**B depicts example data structures within nodes **410** and **412** of tree **290**. Node **410** includes header data **500**B and field value location **560**B. Node **412** includes header data **500**C and field value location **560**C.

As shown in FIG. **5**B, field value locations **560**B and **560**C within respective adjacent leaf nodes **410** and **412** reference the same offset "0x29" in leaf value collection **252**B, or the leaf value "Brown". Thus, both the "hair_color" and "eye_color" leaf nodes for the "John" person parent object reference "Brown" as a shared value that is stored once in leaf value collection **252**B. This stream optimized deduplication reduces the storage footprint of leaf value collection **252**B while minimizing additional processing overhead, since each additional leaf node value only needs to be compared to the last leaf value of its parent node to perform deduplication by sharing the same value offset.

Process for Converting JSON to OSON

FIG. **6** is a flow diagram that depicts an example process **600** that database management system **110** may perform to convert text JSON file **142** into OSON file **134**.

Referring to FIG. **1**A, in block **610**, database management system **110** receives a request to convert text JSON file **142**, comprising a hierarchy of nodes as shown in FIG. **1**B, into OSON file **134** for use by database management system **110**. For example, as described above, client device **140** may send a request to database management system **110** to convert text JSON file **142** into OSON file **134**. Alternatively, JSON to OSON converter **160** may be stored locally on client device **140**, in which case client device **140** may perform process **600**.

Referring to FIG. **4**, in block **612**, database management system **110** generates tree **290** of the hierarchy of nodes from text JSON file **142**, wherein tree **290** references a plurality of leaf values from text JSON file **142**. A specific storage format of the leaf values is further defined depending on whether the leaf values are compressed or deduplicated in a stream or space optimized manner, as discussed in further blocks of process **600**.

In block **614**, database management system **110** determines whether OSON file **134** is to be compressed or uncompressed. When OSON file **134** is to be compressed, process **600** continues to block **616**. Otherwise, when OSON file **134** is to be uncompressed, process **600** continues to block **620**.

Referring to FIG. **1**A and FIG. **4**, in block **616**, database management system **110** uses relative offset generator **182** of compressed converter **180** to embed relative node jump offsets **490** when generating tree **290** to enable navigation of tree **290**. For example, referring to node **422** of FIG. **5**A, each parent node of tree **290** may include a child node mapping **550** that includes relative node jump offsets.

Referring to FIG. **1**A and FIG. **2**, in block **618**, database management system **110** uses data compressor **184** of compressed converter **180** to store tree **290** in relative offset format **280** within compressed container **260**. As discussed above, relative offset format **280** provides a lower data entropy to enable a higher compression ratio for compressed container **260**. Optionally, leaf value mapping **274** may also be included in relative offset format **280**.

Referring to FIG. **1**A, in block **620**, database management system **110** uses mutable JSON detector **172** to determine whether text JSON file **142** is mutable or immutable. When text JSON file **142** is mutable, process **600** continues to block **622**. Otherwise, when text JSON file **142** is immutable, process **600** continues to block **624**. As discussed above, mutable JSON detector **172** may detect certain data types, such as blockchain blocks, as immutable, or the immutable property may be defined with the request in block **602**.

Referring to FIG. **1**A and FIG. **2**, in block **622**, database management system **110** uses stream optimized leaf value deduplicator **174** to generate stream optimized leaf deduplication **250** such that adjacent leaf nodes with duplicate leaf values in tree **290** reference a single shared leaf value. An example is shown in FIG. **5**B, wherein nodes **410** and **412** reference a single shared leaf value "Brown" in leaf value collection **252**B.

Referring to FIG. **1**A and FIG. **2**, in block **624**, database management system **110** uses space optimized leaf value deduplicator **176** to generate space optimized leaf deduplication **230** such that at least a subset of the leaf values referenced by tree **290** is unique. For example, referring to leaf value collection **232** in FIG. **3**B, it can be observed that the leaf values are unique for each leaf value. In some embodiments, size filter **178** may be used such that only a subset of the leaf values not exceeding a leaf size threshold are unique.

Referring to FIG. **1**A, in block **626**, database management system **110** stores the deduplicated leaf values from block **622** or block **624** into OSON file **134**. For example, referring to FIG. **2** and FIG. **3**B, when block **622** was performed, leaf value collection **232** of stream optimized leaf deduplication **250** is stored in OSON file **134**B. Referring to FIG. **2** and FIG. **3**D, when block **624** was performed, leaf value collection **252**B of space optimized leaf deduplication **230** is stored in OSON file **134**C.

Database Overview

Embodiments of the present invention are used in the context of database management systems (DBMSs). Therefore, a description of an example DBMS is provided.

Generally, a server, such as a database server, is a combination of integrated software components and an allocation of computational resources, such as memory, a node, and processes on the node for executing the integrated software components, where the combination of the software and computational resources are dedicated to providing a particular type of function on behalf of clients of the server. A database server governs and facilitates access to a particular database, processing requests by clients to access the database.

A database comprises data and metadata that is stored on a persistent memory mechanism, such as a set of hard disks. Such data and metadata may be stored in a database logically, for example, according to relational and/or object-relational database constructs.

Users interact with a database server of a DBMS by submitting to the database server commands that cause the database server to perform operations on data stored in a database. A user may be one or more applications running on a client computer that interact with a database server. Multiple users may also be referred to herein collectively as a user.

A database command may be in the form of a database statement. For the database server to process the database statements, the database statements must conform to a database language supported by the database server. One non-limiting example of a database language that is supported by many database servers is SQL, including proprietary forms of SQL supported by such database servers as Oracle, (e.g. Oracle Database **11***g*). SQL data definition language ("DDL") instructions are issued to a database server to create or configure database objects, such as tables, views, or complex types. Data manipulation language ("DML") instructions are issued to a DBMS to manage data stored within a database structure. For instance, SELECT, INSERT, UPDATE, and DELETE are common examples of DML instructions found in some SQL implementations. SQL/XML is a common extension of SQL used when manipulating XML data in an object-relational database.

Generally, data is stored in a database in one or more data containers, each container contains records, and the data within each record is organized into one or more fields. In relational database systems, the data containers are typically referred to as tables, the records are referred to as rows, and the fields are referred to as columns. In object-oriented databases, the data containers are typically referred to as object classes, the records are referred to as objects, and the fields are referred to as attributes. Other database architectures may use other terminology. Systems that implement the present invention are not limited to any particular type of data container or database architecture. However, for the purpose of explanation, the examples and the terminology used herein shall be that typically associated with relational or object-relational databases. Thus, the terms "table", "row" and "column" shall be used herein to refer respectively to the data container, record, and field.

Query Optimization and Execution Plans

Query optimization generates one or more different candidate execution plans for a query, which are evaluated by the query optimizer to determine which execution plan should be used to compute the query.

Execution plans may be represented by a graph of interlinked nodes, each representing an plan operator or row sources. The hierarchy of the graphs (i.e., directed tree) represents the order in which the execution plan operators are performed and how data flows between each of the execution plan operators.

An operator, as the term is used herein, comprises one or more routines or functions that are configured for performing operations on input rows or tuples to generate an output set of rows or tuples. The operations may use interim data structures. Output set of rows or tuples may be used as input rows or tuples for a parent operator.

An operator may be executed by one or more computer processes or threads. Referring to an operator as performing an operation means that a process or thread executing functions or routines of an operator are performing the operation.

A row source performs operations on input rows and generates output rows, which may serve as input to another row source. The output rows may be new rows, and or a version of the input rows that have been transformed by the row source.

A match operator of a path pattern expression performs operations on a set of input matching vertices and generates a set of output matching vertices, which may serve as input to another match operator in the path pattern expression. The match operator performs logic over multiple vertex/edges to generate the set of output matching vertices for a specific hop of a target pattern corresponding to the path pattern expression.

An execution plan operator generates a set of rows (which may be referred to as a table) as output and execution plan operations include, for example, a table scan, an index scan, sort-merge join, nested-loop join, filter, and importantly, a full outer join.

A query optimizer may optimize a query by transforming the query. In general, transforming a query involves rewriting a query into another semantically equivalent query that should produce the same result and that can potentially be executed more efficiently, i.e. one for which a potentially more efficient and less costly execution plan can be generated. Examples of query transformation include view merging, subquery unnesting, predicate move-around and push-down, common subexpression elimination, outer-to-inner join conversion, materialized view rewrite, and star transformation.

Hardware Over View

According to one embodiment, the techniques described herein are implemented by one or more special-purpose computing devices. The special-purpose computing devices may be hard-wired to perform the techniques, or may include digital electronic devices such as one or more application-specific integrated circuits (ASICs) or field programmable gate arrays (FPGAs) that are persistently programmed to perform the techniques, or may include one or more general purpose hardware processors programmed to perform the techniques pursuant to program instructions in firmware, memory, other storage, or a combination. Such special-purpose computing devices may also combine custom hard-wired logic, ASICs, or FPGAs with custom programming to accomplish the techniques. The special-purpose computing devices may be desktop computer systems, portable computer systems, handheld devices, networking devices or any other device that incorporates hard-wired and/or program logic to implement the techniques.

For example, FIG. 7 is a block diagram that illustrates a computer system **700** upon which an embodiment of the invention may be implemented. Computer system **700** includes a bus **702** or other communication mechanism for communicating information, and a hardware processor **704** coupled with bus **702** for processing information. Hardware processor **704** may be, for example, a general purpose microprocessor.

Computer system **700** also includes a main memory **706**, such as a random access memory (RAM) or other dynamic storage device, coupled to bus **702** for storing information and instructions to be executed by processor **704**. Main memory **706** also may be used for storing temporary variables or other intermediate information during execution of instructions to be executed by processor **704**. Such instructions, when stored in non-transitory storage media accessible to processor **704**, render computer system **700** into a special-purpose machine that is customized to perform the operations specified in the instructions.

Computer system **700** further includes a read only memory (ROM) **708** or other static storage device coupled to bus **702** for storing static information and instructions for processor **704**. A storage device **710**, such as a magnetic disk, optical disk, or solid-state drive is provided and coupled to bus **702** for storing information and instructions.

Computer system **700** may be coupled via bus **702** to a display **712**, such as a cathode ray tube (CRT), for displaying information to a computer user. An input device **714**, including alphanumeric and other keys, is coupled to bus **702** for communicating information and command selections to processor **704**. Another type of user input device is cursor control **716**, such as a mouse, a trackball, or cursor direction keys for communicating direction information and command selections to processor **704** and for controlling cursor movement on display **712**. This input device typically has two degrees of freedom in two axes, a first axis (e.g., x) and a second axis (e.g., y), that allows the device to specify positions in a plane.

Computer system **700** may implement the techniques described herein using customized hard-wired logic, one or more ASICs or FPGAs, firmware and/or program logic which in combination with the computer system causes or programs computer system **700** to be a special-purpose machine. According to one embodiment, the techniques herein are performed by computer system **700** in response to processor **704** executing one or more sequences of one or more instructions contained in main memory **706**. Such instructions may be read into main memory **706** from another storage medium, such as storage device **710**. Execution of the sequences of instructions contained in main memory **706** causes processor **704** to perform the process steps described herein. In alternative embodiments, hard-wired circuitry may be used in place of or in combination with software instructions.

The term "storage media" as used herein refers to any non-transitory media that store data and/or instructions that cause a machine to operate in a specific fashion. Such storage media may comprise non-volatile media and/or volatile media. Non-volatile media includes, for example, optical disks, magnetic disks, or solid-state drives, such as storage device **710**. Volatile media includes dynamic memory, such as main memory **706**. Common forms of storage media include, for example, a floppy disk, a flexible disk, hard disk, solid-state drive, magnetic tape, or any other magnetic data storage medium, a CD-ROM, any other optical data storage medium, any physical medium with patterns of holes, a RAM, a PROM, and EPROM, a FLASH-EPROM, NVRAM, any other memory chip or cartridge.

Storage media is distinct from but may be used in conjunction with transmission media. Transmission media participates in transferring information between storage media. For example, transmission media includes coaxial cables, copper wire and fiber optics, including the wires that comprise bus **702**. Transmission media can also take the form of acoustic or light waves, such as those generated during radio-wave and infra-red data communications.

Various forms of media may be involved in carrying one or more sequences of one or more instructions to processor **704** for execution. For example, the instructions may initially be carried on a magnetic disk or solid-state drive of a remote computer. The remote computer can load the instructions into its dynamic memory and send the instructions over a telephone line using a modem. A modem local to computer system **700** can receive the data on the telephone line and use an infra-red transmitter to convert the data to an infra-red signal. An infra-red detector can receive the data carried in the infra-red signal and appropriate circuitry can place the data on bus **702**. Bus **702** carries the data to main memory **706**, from which processor **704** retrieves and executes the instructions. The instructions received by main memory **706** may optionally be stored on storage device **710** either before or after execution by processor **704**.

Computer system **700** also includes a communication interface **718** coupled to bus **702**. Communication interface **718** provides a two-way data communication coupling to a network link **720** that is connected to a local network **722**. For example, communication interface **718** may be an integrated services digital network (ISDN) card, cable modem, satellite modem, or a modem to provide a data communication connection to a corresponding type of telephone line. As another example, communication interface **718** may be a local area network (LAN) card to provide a data communication connection to a compatible LAN. Wireless links may also be implemented. In any such implementation, communication interface **718** sends and receives electrical, electromagnetic, or optical signals that carry digital data streams representing various types of information.

Network link **720** typically provides data communication through one or more networks to other data devices. For example, network link **720** may provide a connection through local network **722** to a host computer **724** or to data equipment operated by an Internet Service Provider (ISP) **726**. ISP **726** in turn provides data communication services through the worldwide packet data communication network now commonly referred to as the "Internet" **728**. Local network **722** and Internet **728** both use electrical, electromagnetic, or optical signals that carry digital data streams. The signals through the various networks and the signals on network link **720** and through communication interface **718**, which carry the digital data to and from computer system **700**, are example forms of transmission media.

Computer system **700** can send messages and receive data, including program code, through the network(s), network link **720** and communication interface **718**. In the Internet example, a server **1030** might transmit a requested code for an application program through Internet **728**, ISP **726**, local network **722** and communication interface **718**.

The received code may be executed by processor **704** as it is received, and/or stored in storage device **710**, or other non-volatile storage for later execution.

A computer system process comprises an allotment of hardware processor time, and an allotment of memory (physical and/or virtual), the allotment of memory being for storing instructions executed by the hardware processor, for storing data generated by the hardware processor executing the instructions, and/or for storing the hardware processor state (e.g. content of registers) between allotments of the hardware processor time when the computer system process is not running. Computer system processes run under the control of an operating system, and may run under the control of other programs being executed on the computer system.

In the foregoing specification, embodiments of the invention have been described with reference to numerous specific details that may vary from implementation to implementation. The specification and drawings are, accordingly, to be regarded in an illustrative rather than a restrictive sense. The sole and exclusive indicator of the scope of the invention, and what is intended by the applicants to be the scope of the invention, is the literal and equivalent scope of the set of claims that issue from this application, in the specific form in which such claims issue, including any subsequent correction.

Software Overview

FIG. **8** is a block diagram of a basic software system **800** that may be employed for controlling the operation of computing device **700**. Software system **800** and its components, including their connections, relationships, and functions, is meant to be exemplary only, and not meant to limit implementations of the example embodiment(s). Other software systems suitable for implementing the example embodiment(s) may have different components, including components with different connections, relationships, and functions.

Software system **800** is provided for directing the operation of computing device **700**. Software system **800**, which may be stored in system memory (RAM) **706** and on fixed storage (e.g., hard disk or flash memory) **710**, includes a kernel or operating system (OS) **810**.

The OS **810** manages low-level aspects of computer operation, including managing execution of processes, memory allocation, file input and output (I/O), and device I/O. One or more application programs, represented as **802**A, **802**B, **802**C . . . **802**N, may be "loaded" (e.g., transferred from fixed storage **710** into memory **706**) for execution by the system **800**. The applications or other software intended for use on device **800** may also be stored as a set of downloadable computer-executable instructions, for example, for downloading and installation from an Internet location (e.g., a Web server, an app store, or other online service).

Software system **800** includes a graphical user interface (GUI) **815**, for receiving user commands and data in a graphical (e.g., "point-and-click" or "touch gesture") fashion. These inputs, in turn, may be acted upon by the system **800** in accordance with instructions from operating system **810** and/or application(s) **802**. The GUI **815** also serves to display the results of operation from the OS **810** and application(s) **802**, whereupon the user may supply additional inputs or terminate the session (e.g., log off).

OS **810** can execute directly on the bare hardware **820** (e.g., processor(s) **704**) of device **700**. Alternatively, a hypervisor or virtual machine monitor (VMM) **830** may be interposed between the bare hardware **820** and the OS **810**. In this configuration, VMM **830** acts as a software "cushion" or virtualization layer between the OS **810** and the bare hardware **820** of the device **700**.

VMM **830** instantiates and runs one or more virtual machine instances ("guest machines"). Each guest machine comprises a "guest" operating system, such as OS **810**, and one or more applications, such as application(s) **802**, designed to execute on the guest operating system. The VMM **830** presents the guest operating systems with a virtual operating platform and manages the execution of the guest operating systems.

In some instances, the VMM **830** may allow a guest operating system to run as if it is running on the bare hardware **820** of device **700** directly. In these instances, the same version of the guest operating system configured to execute on the bare hardware **820** directly may also execute on VMM **830** without modification or reconfiguration. In other words, VMM **830** may provide full hardware and CPU virtualization to a guest operating system in some instances.

In other instances, a guest operating system may be specially designed or configured to execute on VMM **830** for efficiency. In these instances, the guest operating system is "aware" that it executes on a virtual machine monitor. In other words, VMM **830** may provide para-virtualization to a guest operating system in some instances.

The above-described basic computer hardware and software is presented for purpose of illustrating the basic underlying computer components that may be employed for implementing the example embodiment(s). The example embodiment(s), however, are not necessarily limited to any particular computing environment or computing device configuration. Instead, the example embodiment(s) may be implemented in any type of system architecture or processing environment that one skilled in the art, in light of this disclosure, would understand as capable of supporting the features and functions of the example embodiment(s) presented herein.

Extensions and Alternatives

Although some of the figures described in the foregoing specification include flow diagrams with steps that are shown in an order, the steps may be performed in any order, and are not limited to the order shown in those flowcharts. Additionally, some steps may be optional, may be performed multiple times, and/or may be performed by different components. All steps, operations and functions of a flow diagram that are described herein are intended to indicate operations that are performed using programming in a special-purpose computer or general-purpose computer, in various embodiments. In other words, each flow diagram in this disclosure, in combination with the related text herein, is a guide, plan or specification of all or part of an algorithm for programming a computer to execute the functions that are described. The level of skill in the field associated with this disclosure is known to be high, and therefore the flow diagrams and related text in this disclosure have been prepared to convey information at a level of sufficiency and detail that is normally expected in the field when skilled persons communicate among themselves with respect to programs, algorithms and their implementation.

In the foregoing specification, the example embodiment(s) of the present invention have been described with reference to numerous specific details. However, the details may vary from implementation to implementation according to the requirements of the particular implement at hand. The example embodiment(s) are, accordingly, to be regarded in an illustrative rather than a restrictive sense.

What is claimed is:

1. A method comprising:

receiving a request to convert a data-interchange file, comprising a hierarchy of nodes, into a binary file for use by a database management system;

generating a tree representation of the hierarchy of nodes, wherein the tree representation references a plurality of leaf values;

determining whether the binary file is to be compressed or uncompressed;

in response to determining that the binary file is to be compressed:

embedding relative node jump offsets when generating the tree representation to enable navigation of the hierarchy of nodes; and

storing the tree representation within a compressed container of the binary file; and

in response to determining that the binary file is to be uncompressed:

determining whether the data-interchange file is immutable or mutable;

in response to determining that the data-interchange file is immutable, deduplicating the plurality of leaf values in a space optimized manner such that at least a subset of the plurality of leaf values is unique; and

in response to determining that the data-interchange file is mutable, deduplicating the plurality of leaf values in a stream optimized manner such that adjacent leaf nodes with duplicate leaf values in the tree representation reference a single shared leaf value; and

storing the deduplicated plurality of leaf values in the binary file.

2. The method of claim **1**, wherein the at least a subset of the plurality of leaf values comprises each of the plurality of leaf values.

3. The method of claim **1**, wherein deduplicating the plurality of leaf values in the stream optimized manner includes reserving, in the plurality of leaf values, one or more common leaf values including at least one of: null, true, false, empty string, 0, 1, empty object, and empty array.

4. The method of claim **1**, wherein storing the deduplicated plurality of leaf values in the binary file further includes storing the tree representation in the binary file.

5. The method of claim **1**, further comprising:

deduplicating a plurality of field names from the hierarchy of nodes; and

storing the deduplicated plurality of field names in the binary file.

6. The method of claim **1**, wherein deduplicating the plurality of leaf values in the space optimized manner further includes deduplicating array objects in the tree representation in the space optimized manner, and wherein deduplicating the plurality of leaf values in the stream optimized manner further includes deduplicating array objects in the tree representation in the stream optimized manner.

7. The method of claim **1**, further comprising:

generating a lookup data structure for the plurality of leaf values; and

storing the lookup data structure in the binary file.

8. The method of claim **1**, wherein deduplicating the plurality of leaf values in the stream optimized manner includes a size filter to skip deduplicating leaf values above a size threshold.

9. The method of claim **1**, wherein deduplicating the plurality of leaf values in the stream optimized manner includes tracking a last leaf value for each parent node in the tree representation.

10. The method of claim **1**, wherein the data-interchange file comprises a JavaScript Object Notation (JSON) text file.

11. One or more non-transitory storage media storing instructions that, when executed by one or more computing devices, cause:

receiving a request to convert a data-interchange file, comprising a hierarchy of nodes, into a binary file for use by a database management system;

generating a tree representation of the hierarchy of nodes, wherein the tree representation references a plurality of leaf values;

determining whether the binary file is to be compressed or uncompressed;

in response to determining that the binary file is to be compressed:

embedding relative node jump offsets when generating the tree representation to enable navigation of the hierarchy of nodes; and

storing the tree representation within a compressed container of the binary file; and

in response to determining that the binary file is to be uncompressed:

determining whether the data-interchange file is immutable or mutable;

in response to determining that the data-interchange file is immutable, deduplicating the plurality of leaf values in a space optimized manner such that at least a subset of the plurality of leaf values is unique; and

in response to determining that the data-interchange file is mutable, deduplicating the plurality of leaf values in a stream optimized manner such that adjacent leaf nodes with duplicate leaf values in the tree representation reference a single shared leaf value; and

storing the deduplicated plurality of leaf values in the binary file.

12. The one or more non-transitory storage media of claim **11**, wherein the at least a subset of the plurality of leaf values comprises each of the plurality of leaf values.

13. The one or more non-transitory storage media of claim **11**, wherein deduplicating the plurality of leaf values in the stream optimized manner includes reserving, in the plurality of leaf values, one or more common leaf values including at least one of: null, true, false, empty string, 0, 1, empty object, and empty array.

14. The one or more non-transitory storage media of claim **11**, wherein storing the deduplicated plurality of leaf values in the binary file further includes storing the tree representation in the binary file.

15. The one or more non-transitory storage media of claim **11**, further comprising:

deduplicating a plurality of field names from the hierarchy of nodes; and

storing the deduplicated plurality of field names in the binary file.

16. The one or more non-transitory storage media of claim **11**, wherein deduplicating the plurality of leaf values in the space optimized manner further includes deduplicating array objects in the tree representation in the space optimized manner, and wherein deduplicating the plurality of leaf values in the stream optimized manner further includes deduplicating array objects in the tree representation in the stream optimized manner.

17. The one or more non-transitory storage media of claim **11**, further comprising:

generating a lookup data structure for the plurality of leaf values; and

storing the lookup data structure in the binary file.

18. The one or more non-transitory storage media of claim **11**, wherein deduplicating the plurality of leaf values in the stream optimized manner includes a size filter to skip deduplicating leaf values above a size threshold.

19. The one or more non-transitory storage media of claim **11**, wherein deduplicating the plurality of leaf values in the stream optimized manner includes tracking a last leaf value for each parent node in the tree representation.

20. The one or more non-transitory storage media of claim **11**, wherein the data-interchange file comprises a JavaScript Object Notation (JSON) text file.

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